BOSTON-LOGAN INTERNATIONAL AIRPORT
ENVIRONMENTAL IMPACT STUDY

VOLUME II

LANDRUM & BROWN, INC.

BOSTON-LOGAN INTERNATIONAL AIRPORT ENVIRONMENTAL IMPACT STUDY

VOLUME II

278

BOSTON-LOGAN INTERNATIONAL AIRPORT ENVIRONMENTAL IMPACT STUDY

VOLUME II

Submitted To

MASSACHUSETTS PORT AUTHORITY

MAY, 1971

By

LANDRUM & BROWN, INC.

THIS ENVIRONMENTAL IMPACT STUDY

IS PRESENTED IN TWO VOLUMES

VOLUME I - Presents Detailed Reports of Studies Performed by the Consulting Team

VOLUME II - Presents Additional Research Reports Prepared by the Consulting Team and by the Massachusetts Port Authority

APPENDIX A

AIRPORT CAPACITY AND DELAY ANALYSIS

For

BOSTON LOGAN INTERNATIONAL AIRPORT

Prepared For

LANDRUM & BROWN

And

MASSACHUSETTS PORT AUTHORITY

R. DIXON SPEAS ASSOCIATES, INC.
MAY 1971

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LIST OF EXHIBITS FOR APPENDIX A

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LIST OF EXHIBITS (continued)

1. INTRODUCTION

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This report presents the results of several analyses of Boston Logan International Airport. Comparisons have been made between the existing airport and the improved airport with Runway 15L/33R added, and other improvements. Since the continuing growth in demand requires greater airport capacity, the objective has been to evaluate the increase in capacity and benefits with the addition of Runway 15L/33R, while maximizing the percentage of overwater approaches and departures (and thereby achieving maximum noise abatement). The analyses cover:

- Preferential runway use to maximize noise abatement.
- Capacity as it varies with runway use to alleviate noise, aircraft population changes to include wide body jets, and future air traffic control improvements.
- The delay to operations resulting from the above capacity variations.
- The use of STOL aircraft.

2. SUMMARY AND CONCLUSIONS

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2.1 The proposed Runway 15L/33R is needed to provide additional capacity required to meet air traffic growth at Boston-Logan Airport, and to provide a greater use of overwater approaches and departures. With the added Runway 15L/33R, overwater operations to the southeast over Massachusetts Bay can be doubled.

2.2 The preferential runway use program now in use at Logan Airport has achieved substantial noise abatement. The program can be revised to provide still further substantial increases in use of overwater approaches and departures, by adding the new factor to runway use criteria of selecting runways in relation to operating rate (demand). This maximizes noise abatement but costs the airport user additional delay.

The revised preferential program assigns specific runways for each wind condition. Further, to increase overwater operations, use is made of less efficient runway combinations in off-peak hours, both day and night.

To forecast the future use of runways with the revised preferential program a five year period of hourly weather reports was analyzed by day and night and by season, and in conjunction with the forecast hourly operating rates. The table below indicates the increase achievable in overwater operations by use of 33R/L and 15R/L runways, and the use of other runways:

	Arrival Runways		
	33R/L	4R/L & 27	Other
. Approaches based on the ten year history	25.1	36.7	38.2
. Approaches forecast when Runway 15L/33R comes into operation and a revised preferential program is used	53.7	18.2	28.1

	Departure Runways		
	15R/L	22R/L & 9	Other
. Departures based on the ten year history	14.6	37.0	48.4
. Departures forecast in 1975 with Runway 15R/33L in operation and a revised preferential program in use	26.7	36.1	37.2

2.3 Airport capacity is reduced appreciably by the introduction of the limiting effects of wide bodied jets due to wake turbulence, with some additional reduction in capacity resulting from the proposed revised preferential runway program. The reduction in capacity is shown in the following table:

Operational Status	Existing Airport	15L/33R Added
Capacity Without Wake Turbulence and Normal Runway Use	368,000	417,000
Capacity With Wake Turbulence Effects Included & Maximum Noise Abatement Runway Use Program	300,000	348,000

2.4 The reduction in capacity due to the wide bodied jets and the revised preferential runway program, results in substantially higher delay to operations. However, the most important difference in delay is that which will result if the new Runway 15L/33R is not constructed. The annual delay to operations has been computed for the demand level of 350,000 with the following results:

- Existing airport with maximum noise abatement runway use program, and wake turbulence effects - 20,575 hours
- Airport with parallel 15L/33R runway added and with maximum noise abatement runway use program, and wake turbulence effects - 11,725 hours

Difference - 8,850 hours (per year)

The increase in delay shown above is conservatively valued at $2,350,000 based on converting the operating cost of aircraft into dollars of cost. In addition, the value of the added hours of delay imposed on users of the airport will be of substantial value (estimated at 470,000 hours).

2.5 Beginning in 1975 and on to the year of about 1980, there will be improvements in control equipment and control techniques which will make possible an increase in airport capacity. This increase is estimated at about 15%.

2.6 STOL aircraft operations can be accommodated at Boston-Logan Airport to operate independently from conventional aircraft on both specially built STOL runways and other unused runways. A substantial increase in airport capacity will result, but this is unlikely to occur before the 1980 time period.

3. TECHNIQUES OF ANALYSIS

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A capacity analysis must include data concerning the current operation of the airport under all wind and weather conditions, and the operation of the airspace and air traffic control system in the metropolitan area.

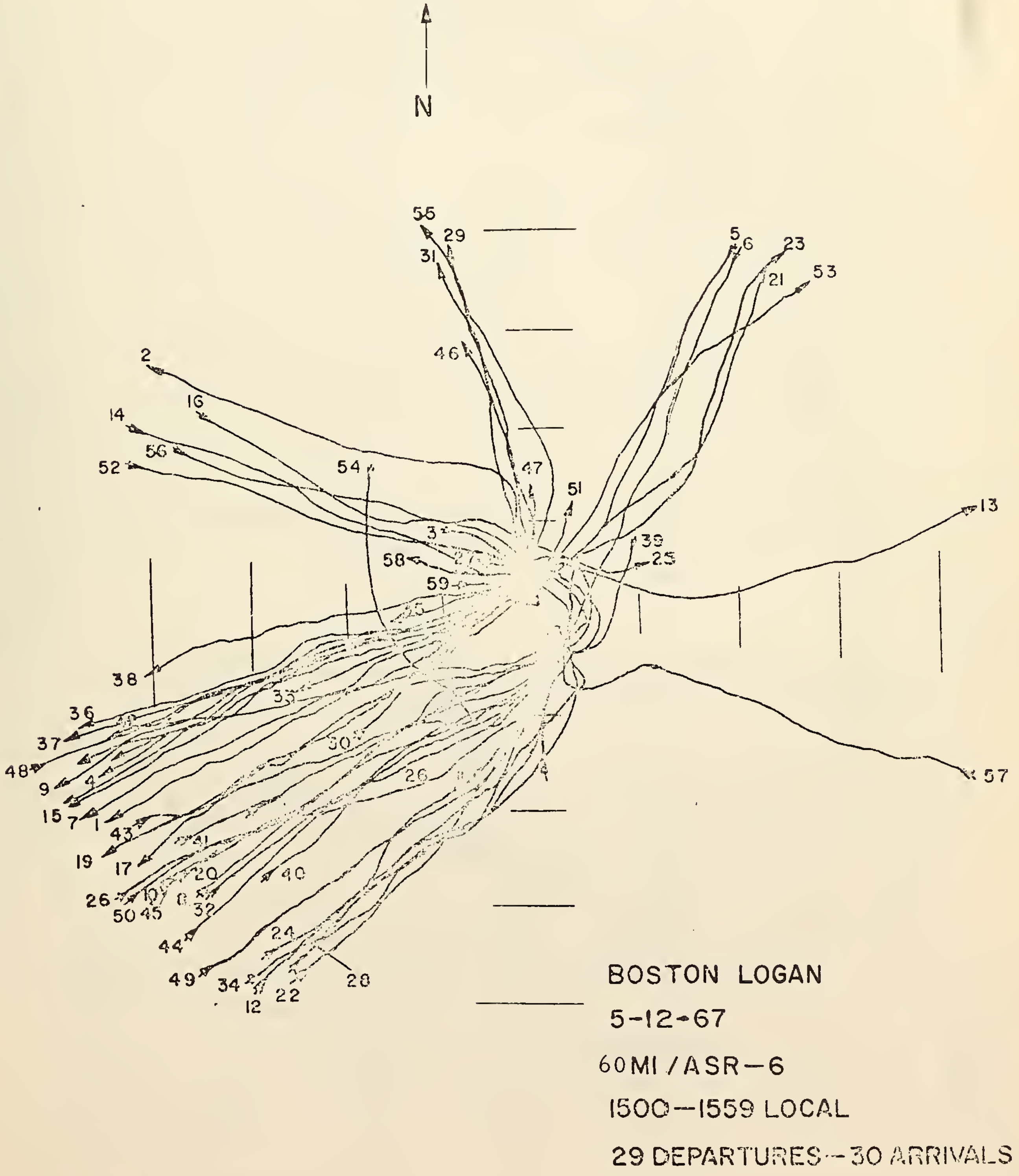
3.1 The Analysis is Based on Field Survey Data

To illustrate the type of information gathered, Exhibit A-1 shows the aircraft operations in the airspace around Boston-Logan Airport on May 12, 1967, for a one-hour period when 59 operations occurred. This illustration is prepared by analyzing photographs of the airport surveillance radar scope at the airport. Each aircraft is tracked on its inbound or outbound route and a number put at the end of the track. A study of this information over several hours provides background needed in understanding any possible limitations of airspace operation on airport capacity, and in projecting airspace use into the future.

3.2 The Analysis Techniques Used Represent Current FAA Practice and Criteria

The capacity analysis technique used is one developed originally for the Federal Aviation Administration beginning in 1959, and which has been expanded over the years and is now the standard reference technique for capacity analysis by the Federal Aviation Administration and other analysts.

FLIGHT TRAVEL DETERMINED BY RADAR PHOTOGRAPHY



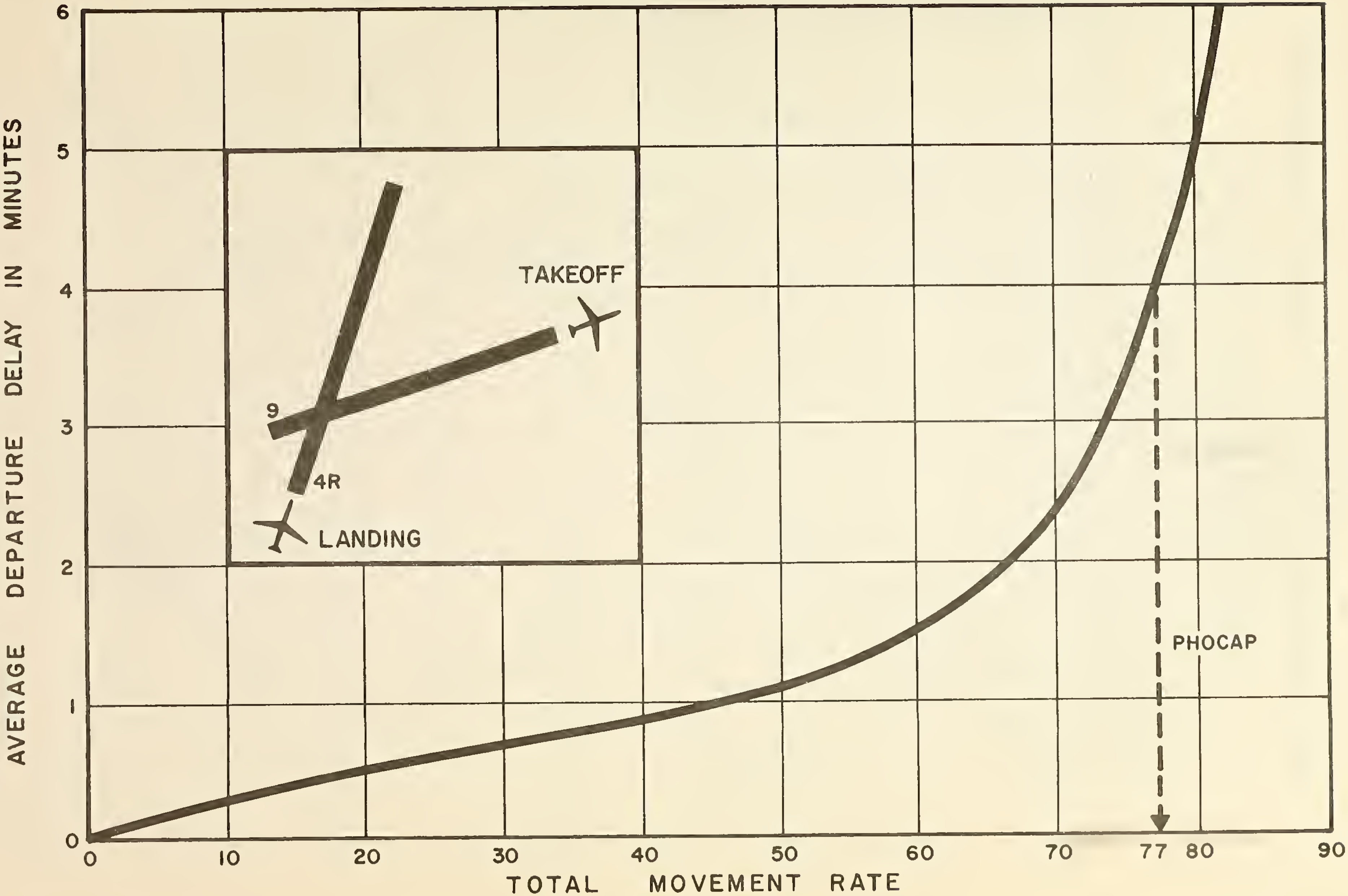
The capacity analysis essentially derives for each runway, or combination of runways that can be used at the airport being studied, a curve which indicates the delay that will result for a given rate of operations on that runway. Exhibit A-2 is an illustration of a typical curve for a runway operation at Boston-Logan International Airport. Notice that for this runway configuration, if 60 movements occur in an hour, the average delay will be about one-and-one half minutes. To determine capacity, it has been found desirable to select the movement rate which results in four minutes average delay and call that the "practical hourly capacity." Note on this Exhibit that the practical hourly capacity occurs at 77 movements per hour. Note also that the movement rate for that runway combination can increase, but a higher delay level results. The use of the four-minute delay level has resulted from consideration of such things as satisfactory service to the community, avoidance of excessive long delay queues on the runways or in the air and cost of operation and delay to the airport users.

3.3 Alternate Modes of Airport Operation Were Analyzed To Determine Their Effects on Capacity

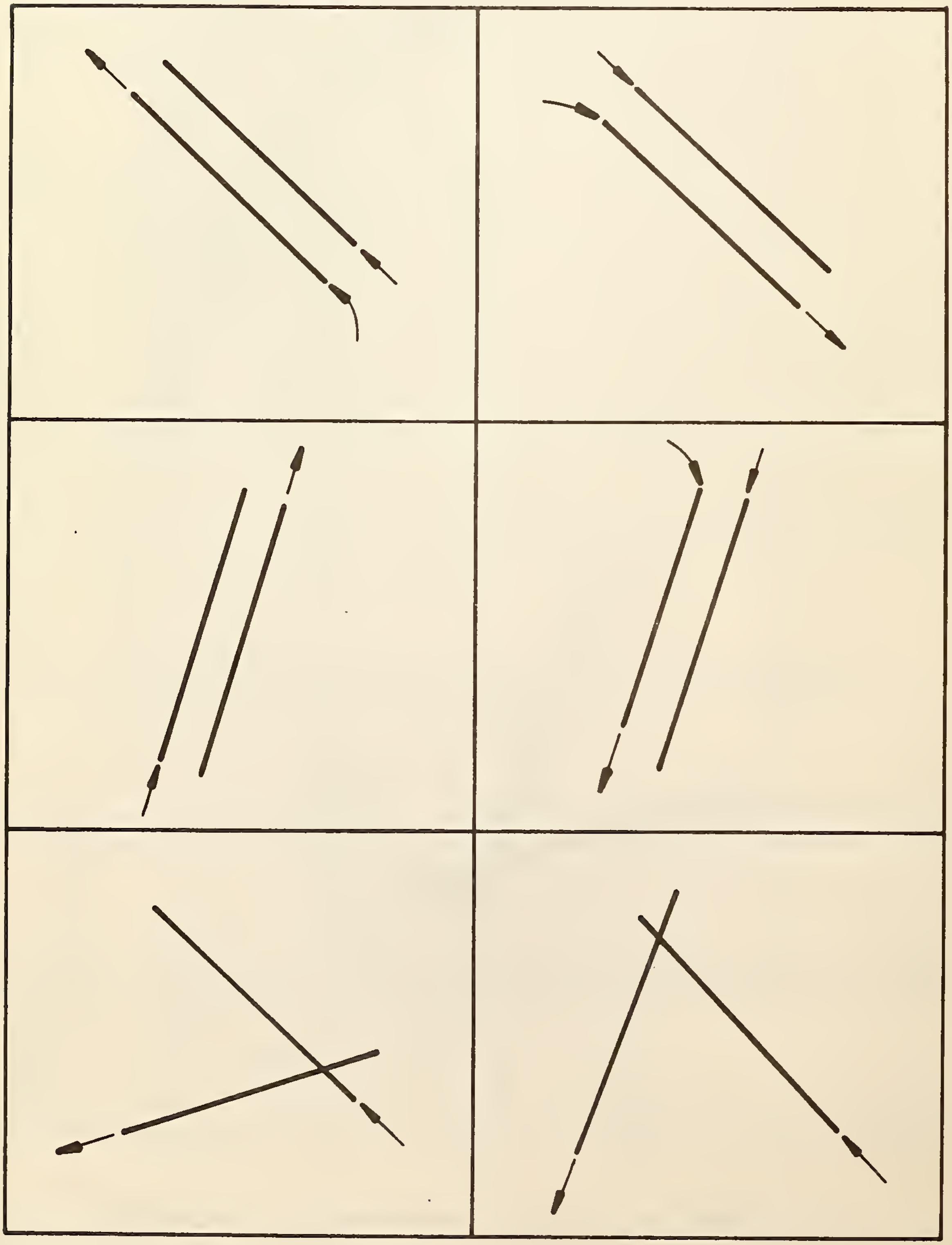
An airport can operate in many different ways in response to the wind and weather conditions. To illustrate the many combinations that are possible, the next two Exhibits depict some of the runway combinations that would be used when a new parallel runway, 15L/33R, has been added and heavy jet aircraft (747 type) are operating in substantial numbers. With reference to Exhibit A-3, note that in the upper left corner Runway 33R is used for the landing of straight-in IFR flight plan approaches and VFR approaches, and runway 33L is used for departure. This efficient runway combination

EXHIBIT A-2

DELAY CURVE COMPLETED TO DETERMINE PHOCAP BOSTON-LOGAN INTERNATIONAL AIRPORT



VFR RUNWAY USAGE – LOGAN AIRPORT WITH PARALLEL 15/33



has an hourly capacity during VFR weather of 74 movements. Similarly, other runway combinations are shown using multiple runways simultaneously. There may be some small number of operations of small aircraft on other runways, but this is limited because of large aircraft wake turbulence. In general, the main use of the runways will be as shown, or in similar combinations. About a 2% use of a single runway occurs with a capacity of 47 per hour.

In Exhibit A-4, runway operation during IFR weather is depicted. It is noted here that it is most efficient to use the parallel runways as the major operation with a capacity of 53 per hour. There may be some small number of operations on the cross runways with lighter aircraft, but in general, the pattern would be the use of the major parallel runways as shown. There will also be minor use of the 9-27 single runway.

It is important to realize the variations in combinations of runways that can be used as shown above, and the resulting variation in capacity.

3.4 The Hourly Variations in Aircraft Demand Were Also Considered

In addition to the variation in capacity that occurs at an airport, there is also a variation in the numbers of aircraft--the demand--that wish to use the airport. Exhibit A-5 depicts this variation. The upper graph shows the variation in demand by hour as a percentage of the peak hour during a typical day. Thus, this indicates that the peak hour for this case occurs between 1600 and 1800, or 4:00 and 6:00 pm, and that a peak of 96% of this afternoon peak

IFR RUNWAY USAGE—LOGAN AIRPORT WITH PARALLEL 15/33

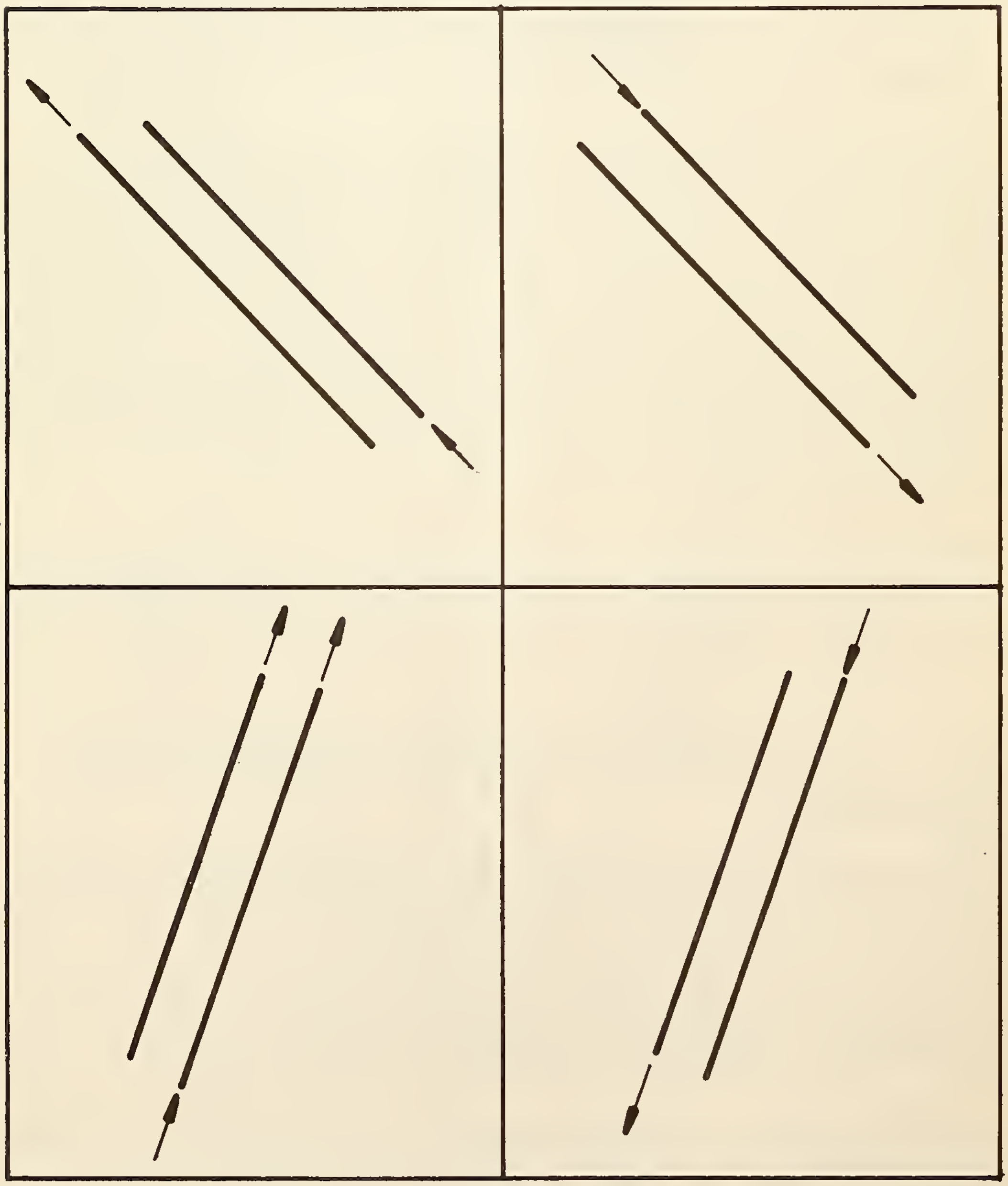
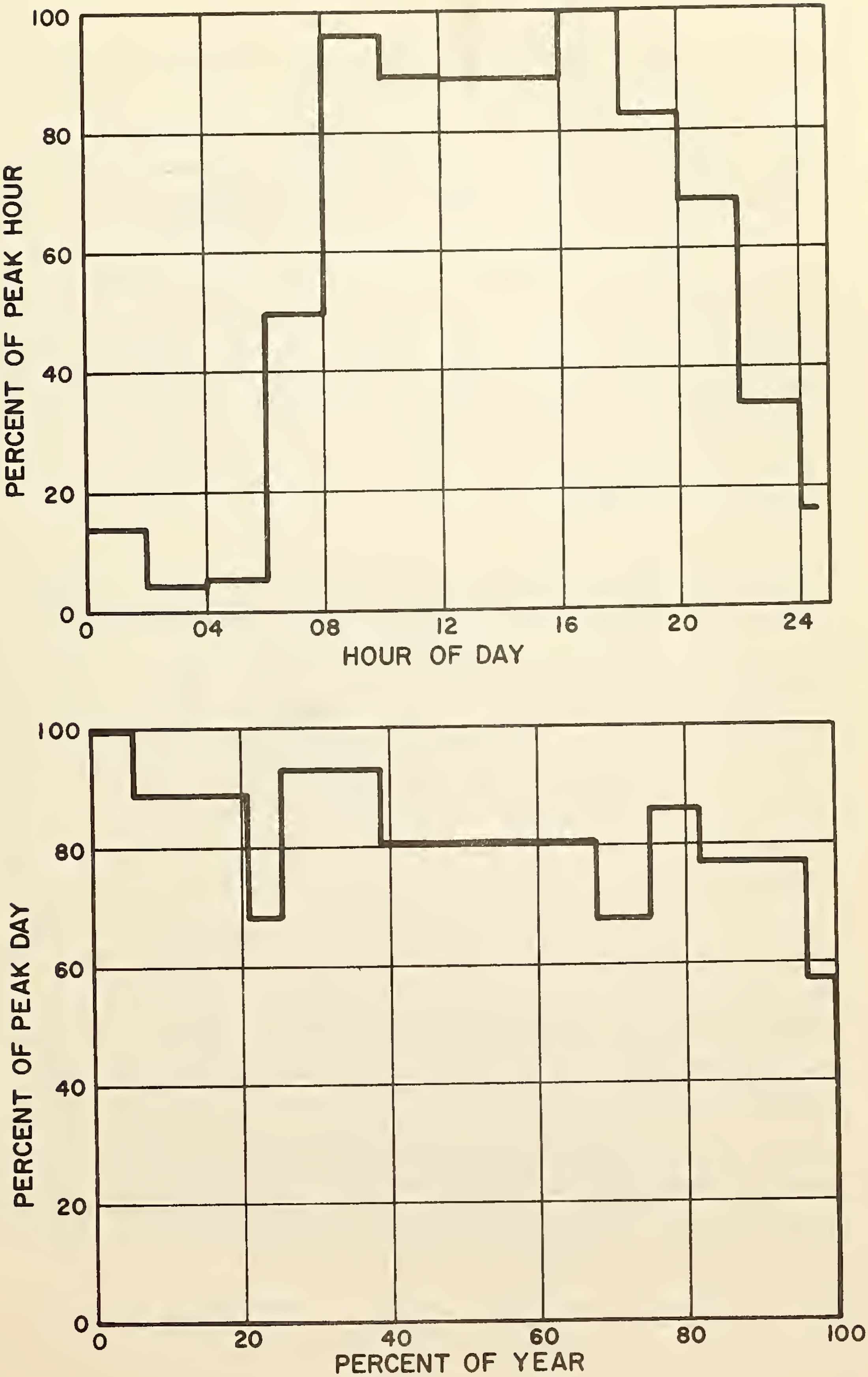


EXHIBIT A-5

DAILY/HOURLY DEMAND VARIATION



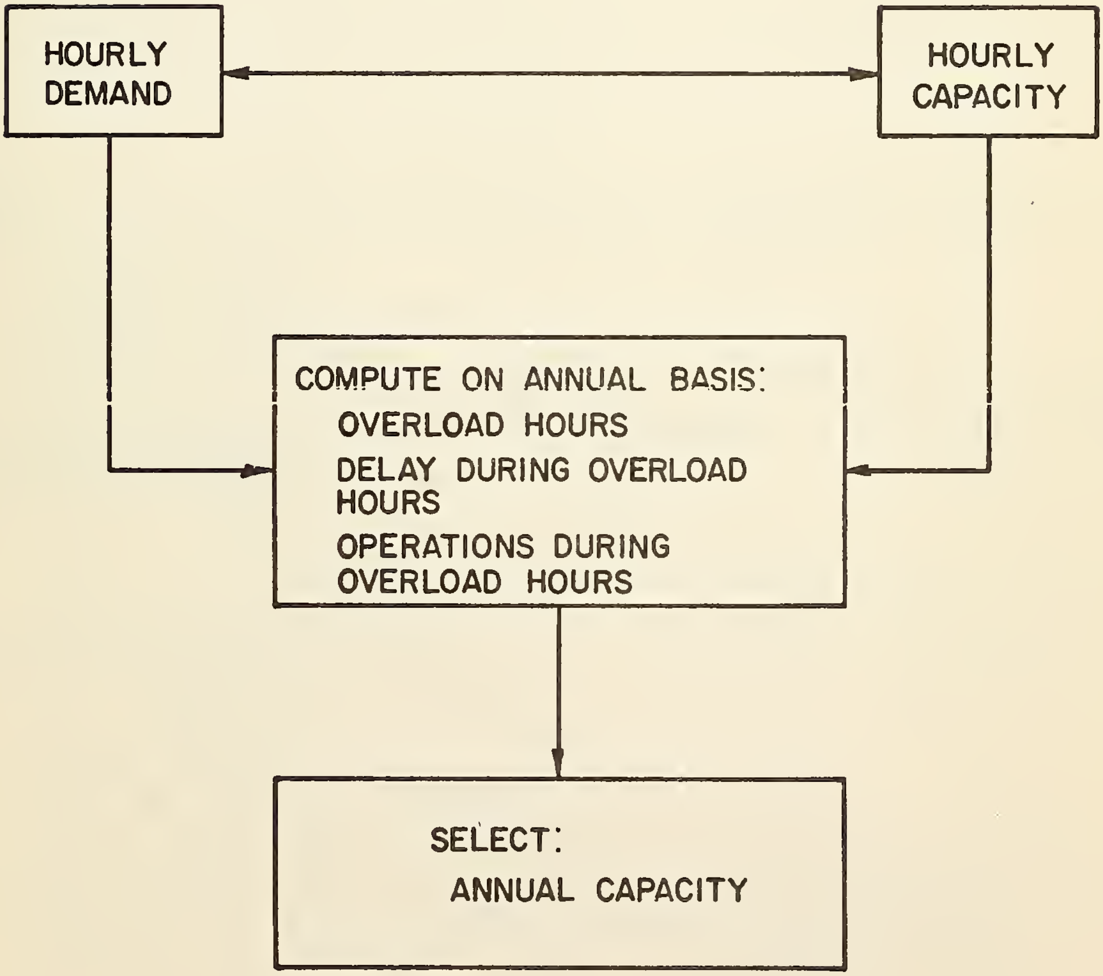
occurs between 8:00 and 10:00 in the morning. Also, that for 12 consecutive hours, the demand is 83% or more of the peak hour - a high continual loading from 8:00 am to 8:00 pm. It is important to the loading of the airport that one understands this variation in hourly demand.

At the bottom of Exhibit A-5, a second graph depicts the variation in daily demand, that is, each day's demand over the period of a year. The daily demand is related to the demand on a peak day which is shown as 100%. The peak day occurs some 7% of the year. Note that the demand varies to about 58% for about 3% of the year, and this occurs during the winter months.

This variation in capacity and the variation in demand makes it difficult to select an hourly number which represents airport capacity. Therefore, it has been found important to develop an annual capacity based on typical operation of the airport with all its hourly capacity variations and hourly demand variations. Exhibit A-6 indicates that this is accomplished by operating the airport for one year through all its hourly demands and hourly capacity variations and computing the overload hours--those hours when delay equals or exceeds four minutes--with the delay during those hours. The level at which the proper limiting delay level occurs is called "the annual capacity." Exhibit A-7 indicates typical annual capacity analysis where the annual capacity, called PANCAP,occurred at 388,000 movements. At this movement rate, about 3-1/2% of the hours in the year would have a delay greater than four minutes, and about 6% of the operations would be subjected to a delay greater than four minutes, and during these hours of overload operation the average delay would be about 12 minutes.

EXHIBIT A-6

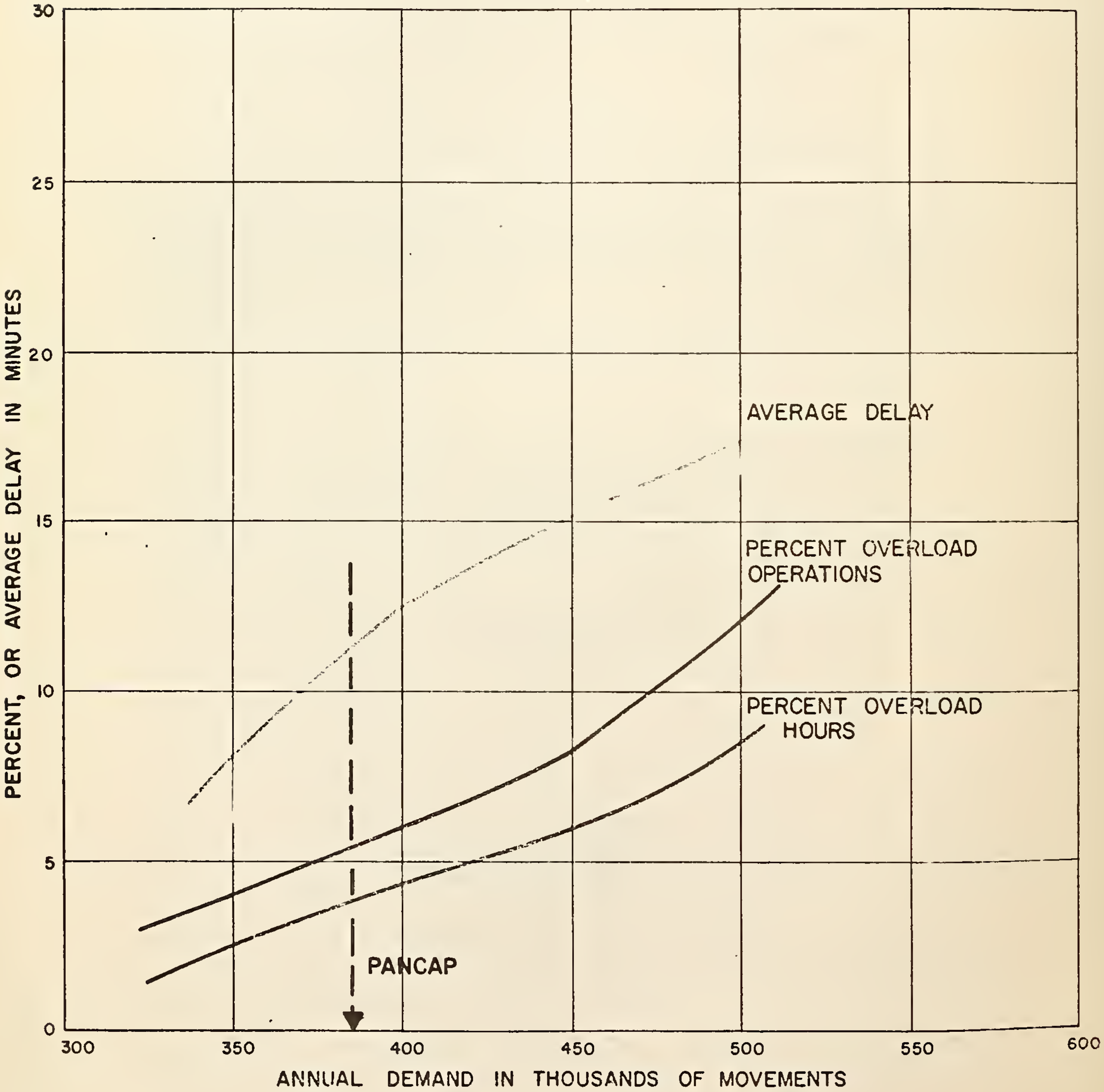
SCHEMATIC OF PANCAP COMPUTATION



APPENDIX B

EXHIBIT A-7

EXAMPLES OF PANCAP COMPUTATION



4. SCOPE OF ANALYSIS

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A variety of airport development stages, operating rules and other factors were analyzed. To achieve a common nomenclature with other study efforts, Exhibit A-8 was prepared to specify 10 "Conditions" to be analyzed. The Conditions 1 through 6 are common to other study analyses. Conditions 5A, 6A, 6B, and 6C have been added to this appendix for further analysis of capacity and delay effects.

Exhibit A-8 includes some definitions. Further definition is given below before discussion of the 10 analyses.

4.1 Airport Configuration

On Exhibit A-8, the terms "existing" and "improved" conform to the airport configurations in Chapter II of the main text, Exhibit II-5.

From the standpoint of the work in this appendix, the key difference is that the improved airport has the added parallel Runway 15L/33R.

4.2 Traffic Demand

From a capacity/delay standpoint, traffic demand will be stated as annual and hourly rates with a specified aircraft population. The aircraft population using an airport has a decided effect on capacity. Generally, the effect is that a runway serving large aircraft will have a lower capacity than one serving small aircraft.

Exhibit A-8

NOMENCLATURE FOR AIRPORT CAPACITY/DELAY ANALYSES
(CONFORMS TO MAIN TEXT NOMENCLATURE)

Condition	1	2	3	4	5	5A	6	6A	6B	6C
Airport Configuration	Existing	Existing	Existing	Exist-ing	Exist-ing	Exist-ing	Im-proved	Im-proved	Im-proved	Im-proved
Traffic Demand	1970	1975	1975	1975	1975	1975	1975	1970	1975	1975
Runway Utilization	Historic	Maximum Capacity	Historic	Noise Abate-ment Alt #1	Noise Abate-ment Alt #2	Noise Abate-ment Alt #2	Maximum Noise Abate-ment	Maximum Capacity	Maximum Capacity	Maximum Noise Abate-ment
Air Traffic Rules	1970	1975	1975	1975	1975	1980	1975	1970	1975	1980

Definitions:

Traffic Demand 1970 uses aircraft population (percent): A-15, B-47, C-13, D+E-25
Traffic Demand 1975 uses aircraft population (percent): AA-13, A-7, B-44, C-11, D+E-25
The Text Section 4.2 describes aircraft classes.
Runway Utilization - See Text Section 4.3
Air Traffic Rules - 1970-Rules Before Wake Turbulence Rules Enacted
1975-Current Rules with Wake Turbulence Rules in Effect
1980-Future Equipment and Reduced Separation Criteria - See Text Section 4.4

Exhibit A-8 indicates the use of two aircraft populations to compute the capacity. The letters designating aircraft types are defined as follows:

AA - Jet aircraft with takeoff gross weight in excess of 300,000 pounds (747, DC-10, L1011, 707-320, DC8-63)

A - 4 engine jet aircraft not included in AA (707, DC-8)

B - Two and three engine air carrier jet aircraft and large propeller aircraft

C - Business jets and large twins (Jet Commander, Grumman Gulfstream I and II, F 27)

D&E- Light twins and single engine aircraft

The basic difference between the two populations is that the one population has no AA aircraft, and would approximate the 1970 population. The population with AA aircraft approximates the 1975 population. Because of operating rules established to guard against the wake turbulence effects of AA aircraft, runway capacity is significantly reduced. The FAA has determined that aircraft weighing more than 300,000 pounds gross weight can cause wake turbulence effects to a degree that aircraft following them in takeoff or landing must have increased separation. The specific rule is quite complex and relates to different runway uses and combinations of aircraft. In general an aircraft weighing less than 300,000 pounds and following the wide body jet in the same operation (that is a takeoff following a takeoff or a landing following a landing) will be required to maintain at least a 2 minute interval on landing and takeoff. This interval of time is substantially greater than normal separations which generally vary from 90 down to 40 seconds for various

maneuvers. The wake turbulence effects (the resulting separation criteria) have been incorporated into the computer programs used to compute capacity. Thus the capacity results show the airport operation both with and without the presence of the large AA aircraft.

4.3 Runway Utilization

This is discussed in detail in Section 5. Below is a brief definition for the terms used in Exhibit A-8 which then are further defined in Section 5:

- "Historic" refers to the current preferential runway use program and which has been in effect for some 10 years.
- "Maximum Capacity" refers to runway use selections based entirely on achieving the highest capacity and minimum delay, and noise abatement is not a consideration.
- "Noise Abatement Alternate #1" refers to a revised preferential runway use program applied to the existing airport wherein runways are selected to maximize overwater approaches, but which uses the parallel 4-22 runways when needed to meet the hourly traffic demand.
- "Maximum Noise Abatement" refers to the revised preferential runway use program attainable with the improved airport, and which results in the highest percentage use of overwater approaches and departures of any of the runway use programs.
- "Noise Abatement Alternate #2" refers to the application to the existing airport of the runway use achieved with "Maximum Noise Abatement".

4.4 Air Traffic Rules

Exhibit A-8 briefly indicates the difference between the time periods 1970, 1975, and 1980 for air traffic rules. The discussion below amplifies the changes expected in air traffic rules.

Current air traffic rules and equipment can be summarized as use of a mixture of manual radar procedures with 3 n. mile minimum spacing, and VFR traffic rules. It has been found that as airports become more heavily loaded, as is predicted for Logan, that traffic handling rates increase. This results from the "pressure factor" wherein both controllers and pilots work together to achieve higher rates to satisfy the higher demand. This increased efficiency has been included in the Logan Airport capacity calculations designated 1975. The effect of wake turbulence rules on capacity is discussed under Aircraft Population 4.2.

It can be expected beginning about 1975 that increases in capacity will be achieved through the use of new equipment and reduced separation criteria. The new equipment is already under contract and is known as Automated Radar Traffic Control System III (ARTS III). This equipment in itself will not have any appreciable effect on capacity, but will provide the capability to increase capacity. The capacity increase will result when the ARTS III equipment is programmed to utilize Metering and Spacing techniques. The benefit of using Metering and Spacing will be that the controllers will be able to more uniformly achieve minimum separation criteria. In addition the Metering and Spacing can be programmed to automate new techniques and use reduced separation criteria. The major new technique will be that

of adjusting arrival spacing to accommodate departures on an efficient basis. Since this technique will increase separation for arrivals in favor of departures, it is known as Delay Sharing.

An appraisal has been made of when these techniques can be assumed to come into operation at Logan Airport, and capacity calculations have been made to assess the benefits from these improvements.

It is estimated that by 1980 there will be substantial improvements in achieving these capacity potentials and they will include the following equipment and techniques:

- ARTS III
- Metering and Spacing
- Delay Sharing
- Reduction in separation criteria to 2.5 n. miles

In the above list, improvements include equipment installation and programming of computers, plus changing regulations to cover both priorities of runway use and reduced runway separation. It will take time to achieve these improvements and we estimate 1980 to be a reasonable year to expect them to be fully operational at Boston Logan Airport. It can be expected that the increase in capacity will begin in approximately 1975 (the ARTS III and Meter and Spacing are in the FAA Facility Installation Program) and the full extent of increase will be obtained about 1980. The capacity analysis is based on achieving all of the above improvements, and so represents the capacity available in 1980.

5. A REVISED PREFERENTIAL RUNWAY USE PROGRAM CAN INCREASE OVERWATER OPERATIONS

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To minimize noise problems, it is desirable to maximize overwater operations. This section suggests a revised preferential program to maximize overwater operations. Several runway utilizations plans are analyzed for both the existing and improved airport.

5.1 Historic Preferential Runway Use

Logan Airport was one of the first airports to establish a preferential runway program. The current program has been in use for some 10 years with improvements being made throughout this period, and in this text the current program is called "historic" preferential runway use.

The historic program can be summarized by repeating below the priority of runway use given the controller as a guide in selecting which runways will be utilized. The priority is stated separately for arrivals and departures and the controller is to select runways in the order of preference given:

- Arrivals - No preference except 22R to be used last
- Departures - 15R, 9, 22R/L, 4R, 33L, 27, 4L

A ten year history of the results of the use of the historic preferential runway program is indicated on Exhibit A-9 where the percentage of approaches and departures on each runway are shown off the ends of each runway.

5.2 Revised Preferential Runway Criteria

Review of the runway use statistics resulting from the historic preferential criteria indicated that it might be possible to increase the overwater runway use by instituting two new concepts as follows:

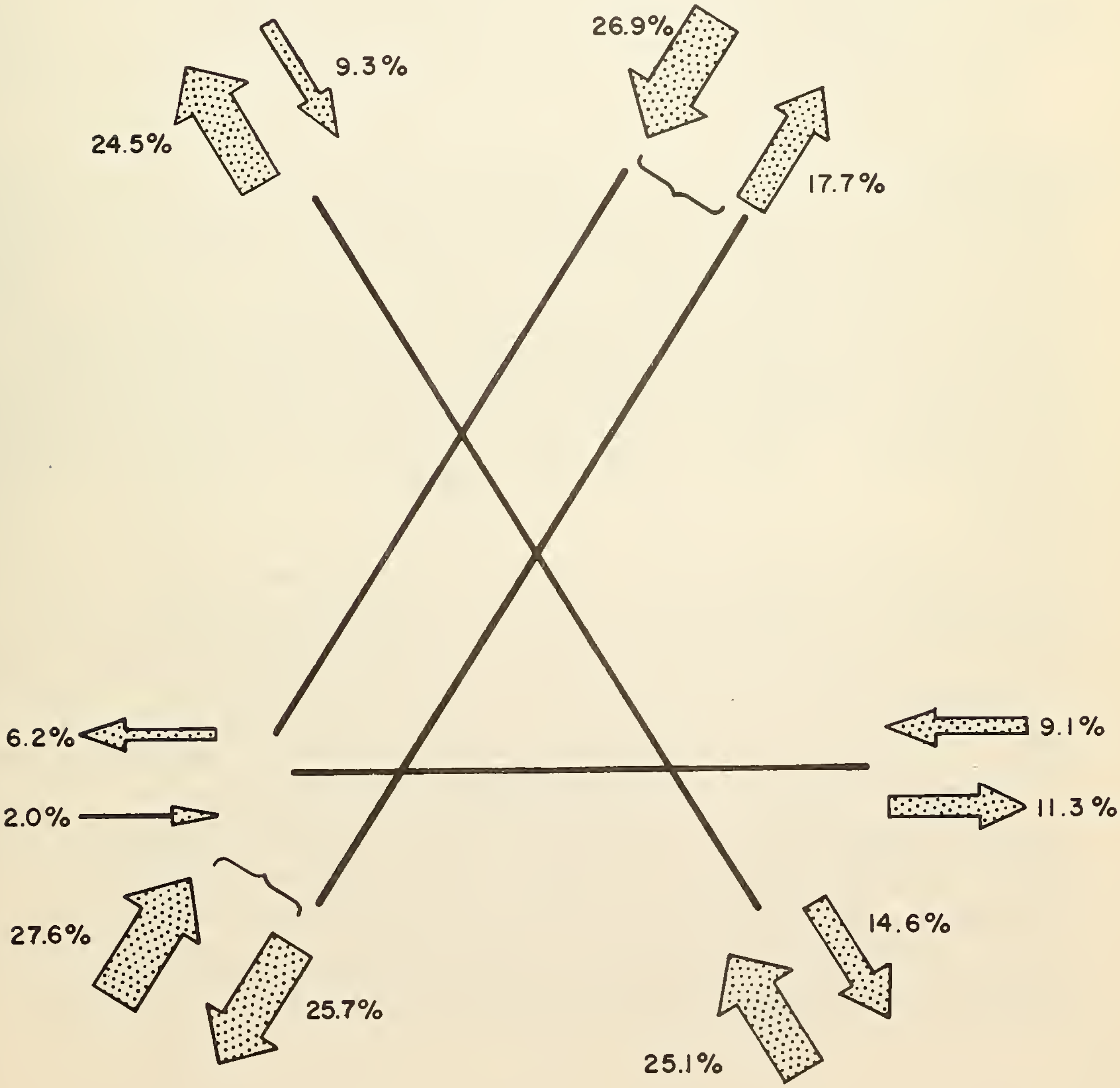
- Assigning specific runway use combinations for specific wind and velocity directions.
- During hours of low demand during the day, and at all times during the night in VFR weather, assigning runway use combinations which maximize overwater operations even though these runway combinations are not the most efficient for that wind condition.

It should be pointed out that the last item of basing runway use on demand during daylight hours is a new concept which is considered workable.

To explore this approach thoroughly, a new weather analysis was accomplished in which the historical weather records for a five year period were analyzed by computer to sort them into day and night periods for the summer months apart from the winter months. Assignment of weather into these categories would permit maximizing the overwater approaches based on hour of the day.

EXHIBIT A-9

RUNWAY USE WITH HISTORIC PREFERENTIAL PROGRAM



SCALE: WIDTH OF ARROW 1" = 100%

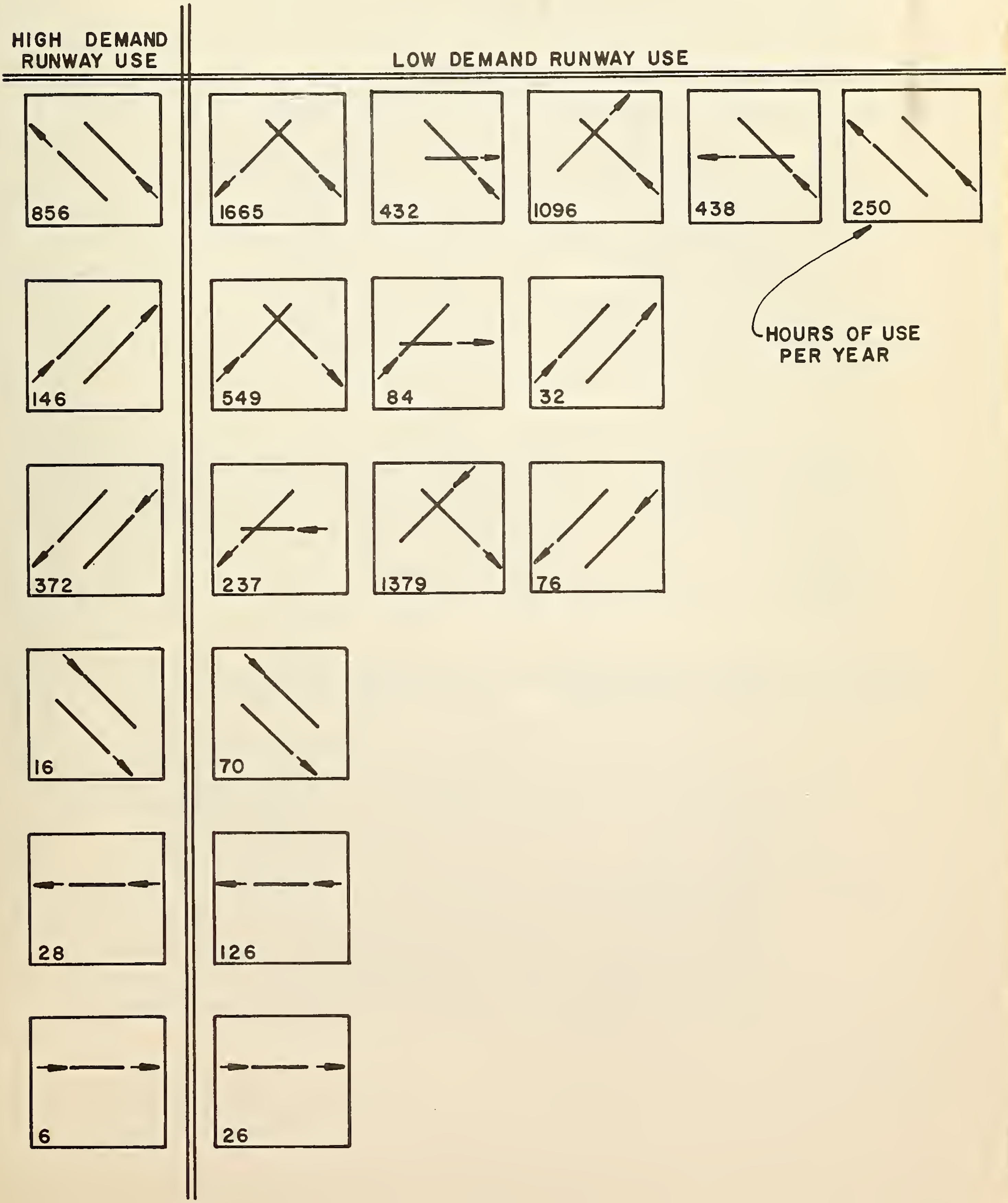
The manner in which runways could best be used was then developed for four conditions, all with a 15 knot crosswind limit -

- the most efficient runway operation using parallel runways wherever possible;
- a less efficient runway use using intersecting or single runways but maximizing overwater operations;
- VFR nighttime operations also maximizing overwater operations;
- IFR operations.

Exhibit A-10 is a typical assignment of runway use against wind direction and velocity to maximize overwater operations during less than peak hour demand situations and for day time use. The exhibit shows the most efficient runway use (used with high demands) for the wind direction, and also the runway use for that wind condition to maximize overwater operations (used during low demands). The hours of use are discussed in the next paragraph.

To derive the hours of use for each runway combination, it was necessary to consider the demand (or aircraft operating level) by hour to determine which hours would have a demand high enough to require parallel runway use. To do this, the entire year was tabulated into the different demand levels which occur, based on seasonal factors. From past experience this has been found to be accomplished by sorting the days into nine different demand levels for the year (as in Exhibit A-5). By examination of demands on an hour by hour basis in the nine daily demand levels, it was possible to assign the numbers of hours when parallel use should be permitted, and the remaining hours when intersecting

VFR RUNWAY CONFIGURATIONS FOR REVISED PREFERENTIAL PROGRAM ON IMPROVED AIRPORT



runways would be used to maximize overwater operations. Exhibit A-10 shows the hours of use for each runway combination at an annual operating rate of 350,000. For example, the first line illustrates the wind condition when the parallel 33L/R runways could be used. The operating rate will be high enough for 856 hours during the year to require parallel operation which includes departure over the Chelsea River area. However, there are four other runway combinations which can be used as shown with landing on Runway 33R and takeoff on an intersecting runway for (as shown) 1,665, 432, 1,096, and 438 hours per year. Another 250 hours must use the parallel runways regardless of demand because the wind requires use of the parallels.

This approach was applied to both the existing airport and the improved airport. For comparison, another runway utilization plan was developed to portray runway usage if the runways are operated to attain maximum capacity. The results are shown in Figures A-11, A-12, and A-13. The basic statistics are contained in Appendix A-1.

5.2.1 Runway Utilization for Existing Airport to Obtain Maximum Capacity

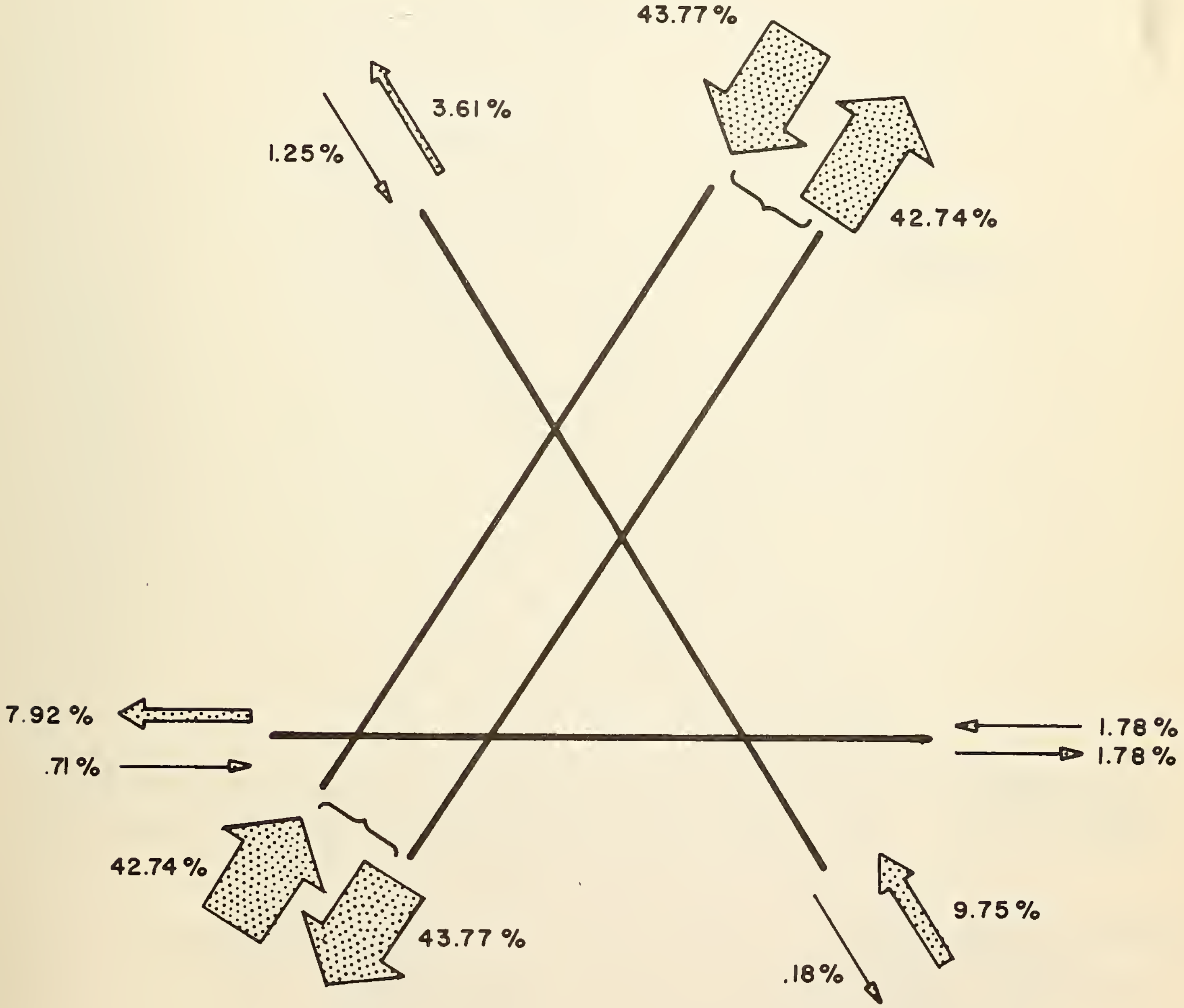
On Figure A-11, note the high use of the 4-22 runway to maximize capacity and minimize delay, and the relatively small use of overwater approaches and departures. This runway use is labelled Maximum capacity.

5.2.2 Runway Utilization with Noise Abatement Alternate No. 1

Figure A-12 shows the existing airport operating to use parallel runways only during peak hours but with these having to be the 4-22 runways. A large improvement in

EXHIBIT A-11

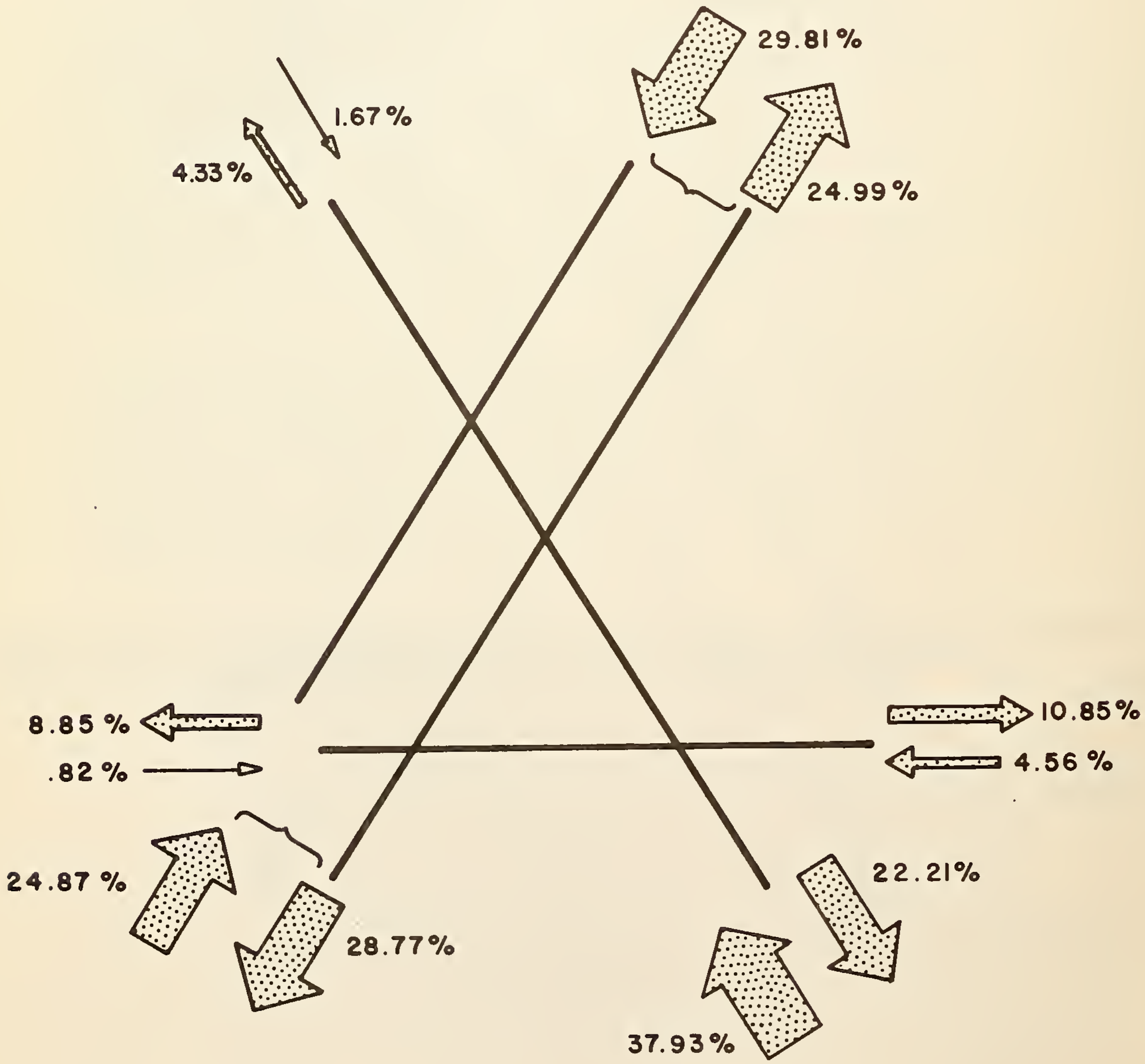
RUNWAY USE FOR EXISTING AIRPORT OPERATED TO ATTAIN MAXIMUM CAPACITY WITH MINIMUM DELAY



SCALE : WIDTH OF ARROW 1"=100%

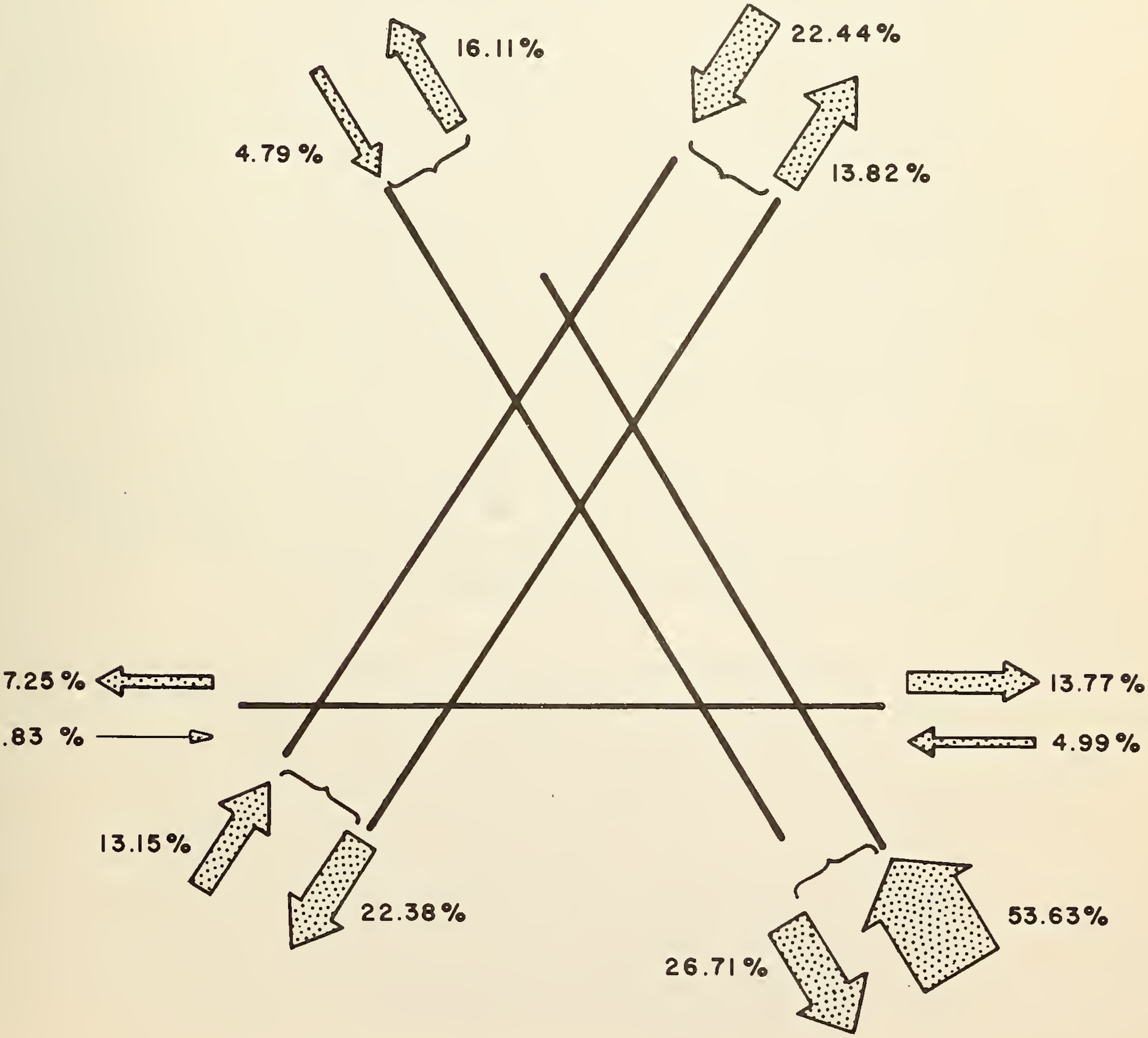
EXHIBIT A-12

RUNWAY USE FOR EXISTING AIRPORT WITH NOISE ABATEMENT ALTERNATE NO.1



SCALE: WIDTH OF ARROW 1" = 100%

RUNWAY USE FOR IMPROVED AIRPORT WITH MAXIMUM NOISE ABATEMENT



NOTE: THE SAME RUNWAY & PERCENTAGES APPLIED TO THE EXISTING AIRPORT IS CALLED "NOISE ABATEMENT ALTERNATE NO. 2"

SCALE: WIDTH OF ARROW 1" = 100%

overwater approaches and departures is possible and shown. This is considered to be a workable runway use program but comment should be made on its attainability. This preferential program is labelled Noise Abatement Alternate No. 1.

It should be noted that much coordination effort is needed to revise the preferential program. The major groups involved are the Federal Aviation Agency, the Massachusetts Port Authority, the airlines, and airline and general aviation pilots. The revised preferential program must be stated in a form readily useable by FAA Control Tower personnel. This will be a pioneering effort because of the use of airport operations level as one factor in choosing the runway use combination.

As shown on Exhibit A-12, appreciable improvement in overwater approach and takeoff use can be achieved on the existing airport, and it is suggested that work toward achieving that improvement should be started.

As to how close the industry can come to attaining the percentages shown on Exhibit A-12, the operating situation should be briefly described. The direction of operation used to meet high demand will be 1) landing and takeoff on the runway 4L/4R combination, and 2) landing and takeoff on the Runway 22L/22R combination. Thus arrivals will be positioned in the air to land on the preferred runway. When demand lowers sufficiently, the landing runway must be changed to the preferred Runway 33, causing a repositioning of arrival streams, (and

departure queues on the ground). When landing demand increases beyond Runway 33 capability, the arrival stream must again be repositioned to land on Runway 4 or 22. This changing of the arrival stream (with less problem involved in changing the departure flow) will make it difficult to achieve the full potential benefits of Noise Abatement Alternate No. 1 Preferential Program.

5.2.3 Runway Utilization with Maximum Noise Abatement

Exhibit A-13 shows the use potentially attainable with the improved airport with Runway 15L-33R available. A still higher use of overwater approaches and departures is possible and this is labelled Maximum Noise Abatement Preferential Program. The probability is good of achieving this degree of overwater runway use. Here, the preferred landing runway for high demand is the same as that for low demand. It is the departure runway which is shifted during low demand periods. For example, when the peak hour situation of having to land and takeoff on Runway 33L/33R is passed, and an intersecting runway combination can be used, landings continue on Runway 33R while departures may be shifted to Runway 22L/R (as shown in Exhibit A-10). The departure shift is relatively easy to accomplish for the demand picture and positioning of departures on the airport is all under Tower Control.

5.2.4 Summary of Runway Use Analyses

The resulting runway use from these alternate plans are summarized in Exhibit A-14. Several items are noteworthy:

- The "Existing Airport-Maximum Capacity" (Column 1)

EXHIBIT A-14

RUNWAY USE STATISTICAL SUMMARY
(In Percent)

	Col. 1		Col. 2		Col. 3		Col. 4	
	Existing Airport Maximum Cap.		Existing Airport Historic Use		Existing Airport Noise Abatement Alt. No. 1		Improved Airport	
Item	Arr.	Dept.	Arr.	Dept.	Arr.	Dept.	Arr.	Dept.
Overwater Operations								
33 - Landing 15 - Takeoff	9.8	.2	25.1	14.6	38.0	22.2	53.7	26.7
Next Preference Use								
4R/L & 27 Landings 22L & 9 Takeoffs	44.5	45.6	36.7	37.0	29.6	39.6	18.2	36.1
Other Runways	45.7	54.2	38.2	48.4	32.4	38.1	28.1	37.2

compared to "Existing-Historic Use" (Column 2) indicates a measure of noise abatement being achieved today, and it is substantial - about 40% overwater (25.1% arrivals plus 14.6% departures) as compared to 10%. Note however, that the arrivals and departures each total 100% in Exhibit A-14.

. The existing with Alternate No. 1 (Column 3) increases the overwater operations to 60%.

. The improved airport raises this to 80% which is about twice that being achieved today, and over half of all arrivals are overwater. This runway use plan thus yields maximum noise abatement.

6. THE PROPOSED AIRPORT IMPROVEMENTS WILL INCREASE LOGAN'S CAPACITY

****

The Conditions listed in Exhibit A-8 have been analyzed for hourly and annual capacity. The results are presented in Exhibit A-15.

Several results on Exhibit A-15 should be noted.

- The most pertinent capacities for the 1971-75 period are conditions 5 and 6 which include the future aircraft population. Note that these are about 17% lower than conditions 1 and 6A and so the difference reflects the effect of AA aircraft and revised preferential runway use.

- Conditions 5A and 6C indicate the increase in capacity by 1980 which is an increase of about 15%.

- Condition #5 assigns runway use to achieve the same percent of overwater operations as condition 6. Were all peak hours of demand accommodated on the parallel Runways 4-22, the PANCAP would increase to 313,000 (condition 4).

- The capacity benefits of the new runway 15L-33R are the increase from 300,000 to 348,000 or a 16% increase and the increases in VFR hourly capacity from 45 to 76 and in IFR from 37 to 53. A greater benefit from the new runway is shown in the delay analysis which follows.

- Conditions 2 and 4 show the same PANCAP although condition 4 is a less efficient runway use than condition 2. This results because PANCAP is related to the number of hours which have an average delay in excess of 4 minutes.

EXHIBIT A-15

CAPACITY ANALYSIS SUMMARY

(See Exhibit A-8 for more complete description of "Condition")

Condition	PANCAP	Peak Hour	PHOCAP Changes For Runway 15-33 VFR	PHOCAP Changes For Runway 15-33 IFR
1 - Existing, 1970, Historic	368,000	91	56	44
2 - Existing, 1975, Maximum Capacity	313,000	73	45	37
3 - Existing, 1975, Historic	N O T	C O M P U T E D		
4 - Existing, 1975, Noise Abatement Alternate No. 1	313,000	73	45	37
5 - Existing, 1975, Noise Abatement Alternate No. 2	300,000	70	45	37
5A- Existing, 1980, Noise Abatement Alternate No. 2	340,000	80	56	56
6 - Improved, 1975, Maximum Noise Abatement	348,000	81	76	53
6A- Improved, 1970, Maximum Capacity	417,000	103	112	60
6B- Improved, 1975, Maximum Capacity	348,000	81	76	53
6C- Improved, 1980, Maximum Noise Abatement	398,000	93	94	82

These hours are the same for both 2 and 4 but the delay in other hours will be greater in condition 4, and the change in delay is shown in Section 8. The same situation exists in relation to conditions 6 and 6B.

7. THE PROPOSED IMPROVEMENTS ARE NEEDED

****

A comparison of future demand and available capacity has been made, and the effect of continued operation beyond capacity has been explored.

Landrum and Brown developed a planning level for annual aircraft operations which is presented in the main text of Chapter II as follows:

1970	300,000
1975	350,000
1980	400,000

The capacity analyses in Chapter 6 show that the capacity of the existing airport is between 300,000 and 368,000 depending on the number of AA (wide-body) aircraft operating and the degree of overwater operation attained. Thus, the airport is nearing capacity today.

The addition of another runway raises the capacity to about 350,000 (348,000) which indicates that capacity will be reached again about 1975. It is noted that the above planning level for 1975 includes only about fifteen percent (15%) general aviation which is about the minimum level to be expected at a busy airport such as Boston-Logan International Airport. Thus, if the planning level of 350,000 is too low, the airport will be above capacity in 1975 with little likelihood of easing demand by further reducing general aviation.

Beginning about 1975, the capacity will increase gradually, due to improved air traffic control capability, to about 400,000 in 1980.

If Boston-Logan International Airport is not improved as proposed, it soon will reach capacity and operate above capacity. How great can the overload become without too great a deterioration in service to the public? There is guidance on this as has been determined by Speas Associates in another study of the capacity of O'Hare Airport (Appendix B of Airport Layout Plans Report - 1971, Chicago-O'Hare International Airport). An evaluation was made of the overload condition existing at O'Hare Airport in 1968 before the current hourly rate limitation was imposed on O'Hare by the FAA. This evaluation determined the degree of overload existing at O'Hare during that period (1968) when high delay conditions existed. This level of delay can reasonably be considered saturation of the airport, since the FAA determined the condition was so serious that it had to be corrected by limiting the hourly operations.

The equivalent overload condition for the existing airport would occur at an operating level of about 350,000. Thus, the existing airport would reach this undesirable level of service in about 1975. The quality of service measured in terms of delay is discussed below.

8. INCREASED CAPACITY IMPROVES THE SERVICES WHICH THE AIRPORT PROVIDES TO THE COMMUNITY

****

There is a substantial improvement in the service the airport can render due to the new runway. Exhibit A-16 indicates the hourly capacity variation over a year's period. The heavy line indicates the capacity variation for the existing airport operating at a PANCAP of 300,000. Note that it starts at 74 movements an hour and as the intersecting (low demand) runway combinations come into use, it decreases to 65 for most of the year and to less than 50 for a small percentage of the time. Similarly, a dotted line above the heavy line indicates the higher capacities available with an added 15-33 runway operating at its PANCAP of 348,000. The shaded area emphasizes the difference in capacity. Note that a line has been plotted at the 81 movements per hour level. This represents the peak hour at the annual capacity of 348,000, which will occur about 23 days each year. The added runway provides parallel runway capacity (86) to exceed this peak day requirement, whereas the existing airport does not. In addition, the major secondary capacity available (74) is 14% above the similar capacity (65) for the existing airport.

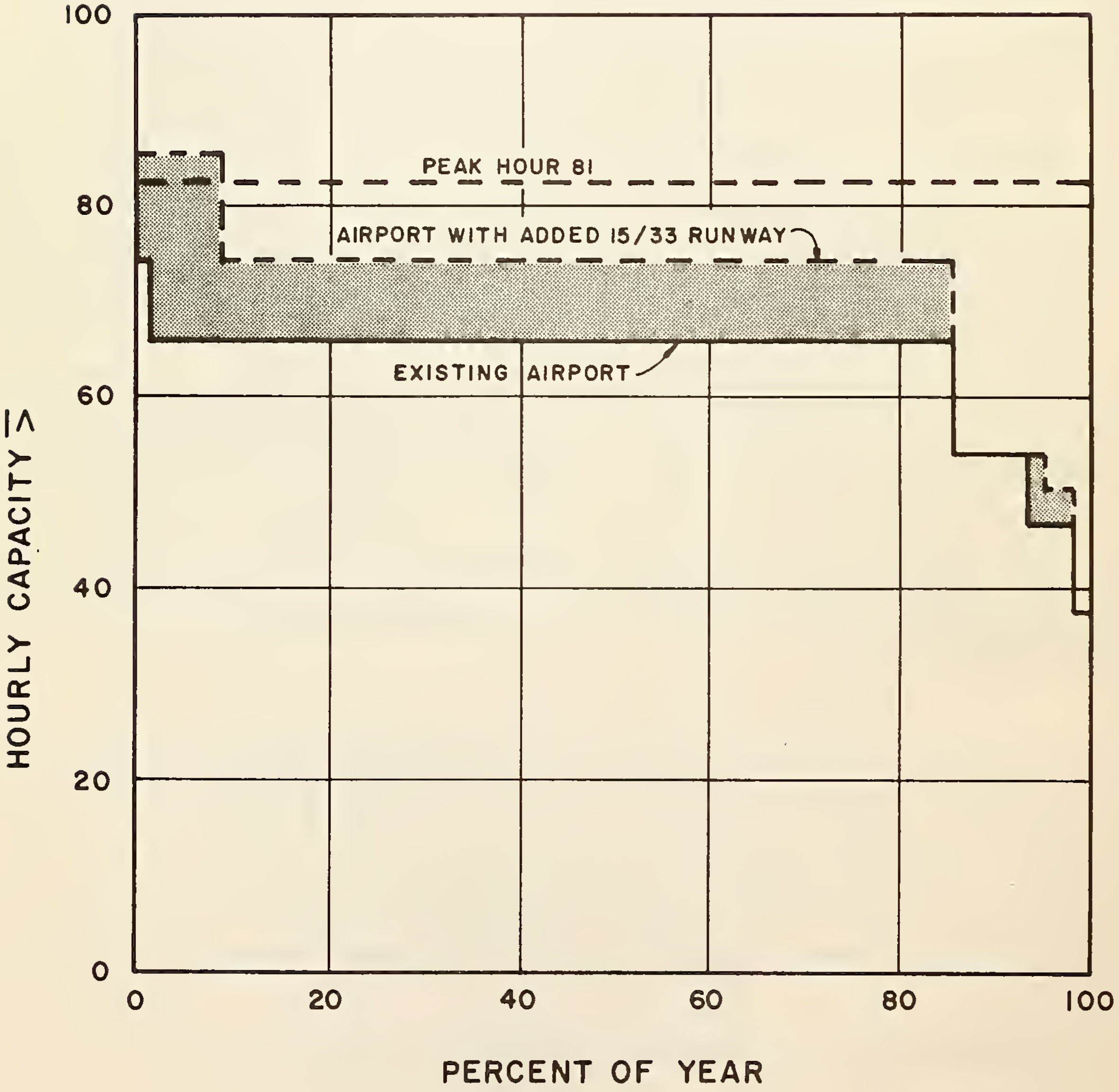
The increased capacity results in substantially less delay, which is important to the air travelers using the airport, as they will not have to wait so long to get off the airport or to return to Logan. Further, without 15L-33R, the airport would operate at a higher delay level causing a shifting of schedules to off-peak hours and resulting in below optimum service to the air traveler.

It is important to examine the delay to operations for the various operating conditions. This delay is a measure of both:

- the benefit of the new runway, and

EXHIBIT A-16

HOURLY CAPACITY VARIATION



- the penalty the aircraft operators will pay in order to provide greater noise relief.

The hours of delay have been computed by hour and by year for several of the conditions of airport configuration and operation. This delay has real economic significance. For this analysis, a dollar value will be attached only to the cost of aircraft operations to the airport user. There is also a cost to the passenger which has not been assessed, except to indicate the conversion of the hours of aircraft delay into hours of passenger delay.

To convert the delay of aircraft operations into dollars, the standard operating cost information published by the Civil Aeronautics Board on hourly aircraft operating costs, along with projected costs for future aircraft have been used. These have been evaluated to charge the following percentage cost in the various operating modes:

- Delay in the air - 67%
- Delay on the ground away from the gate - 45%

The operating costs derived on this basis are considered to be realistic and quite conservative.

A demand level of 350,000 annual movements has been chosen for computation of delay. This is the 1975 planning level and also represents saturation of the present airport for the conditions described earlier. That the present airport will operate beyond this level (before the 1975-1980 air traffic improvements are in being) is unlikely. For because of the high delay level, demand will either voluntarily or involuntarily be restrained. If demand continues to increase beyond 350,000, delay will build rapidly

because of the severe overload on the airport. The chosen demand level of 350,000 also approximates the normal annual capacity of the improved airport.

Exhibit A-17 presents the delay analyses for the pertinent operating conditions using the same analyses as in Exhibits A-8 and A-15. All delays are given for an annual operating rate of 350,000.

Several observations on Exhibit A-17 are pertinent; but the major observation deals with a comparison of the existing and improved airport.

The three delay levels for Conditions 4, 5, and 6 of Exhibit A-17 are of considerable importance:

- Condition 4 with 15,480 hours delay is the delay resulting from the runway use on the Existing Airport depicted on Exhibit A-12 (60% overwater operations). The text (Section 5.2.2) indicated the considerations involved to achieve the runway use shown, and the inefficiencies in operation which might result. Such inefficiencies would increase delay.

- Condition 5 with 20,575 hours delay is the delay resulting from the runway use on the Existing Airport depicted on Exhibit A-13 (80% overwater operations). Since Exhibit A-13 represents the maximizing of overwater operations, and is a practical program for the improved airport, the intent in condition 5 is to determine how costly it is to achieve the same degree of overwater operations with the existing airport.

EXHIBIT A-17

Delay to Operations At An
Annual Demand of 350,000 Movements

Condition No.	Description	Hours of Delay Per Yr.	Cost of Delay
	(See Exhibit 2-8 for complete description of airport staging and operating conditions)		
1	Existing,1970,Historic	6,005	1,607,000
2	Existing,1975,Maximum Capacity	13,120	4,187,000
4	Existing,1975,Noise Abatement Alternate No. 1	15,480	4,800,000
5	Existing,1975,Noise Abatement Alternate No. 2	20,575	6,160,000
6	Improved Airport,1975, Maximum Noise Abatement	11,725	3,810,000
6A	Improved Airport,1970, Maximum Capacity	4,035	1,108,000
6B	Improved Airport,1975, Maximum Capacity	9,640	3,254,000

. Condition 6 with 11,725 hours delay is the delay resulting from the runway use on the Improved Airport depicted on Exhibit A-13. The high use of overwater approaches and departures represents a maximizing of noise abatement from runway use (80% overwater operations). This runway use at this delay level is thus the desirable situation to achieve.

. From the three points above, it is concluded that a fair comparison of the delay cost to achieve maximum noise abatement on the existing airport, and equivalent to that achievable with the improved airport is

Condition 5	20,575 hours	$6,160,000
less Condition 6	11,725	3,810,000
	8,850 hours	$2,350,000

A large improvement in noise abatement is achieved by condition 4, but it is likely the delay shown will increase, and the percentage of overwater operations achieved is lower than with the improved airport.

Other observations of interest are:

. The reduced capacity resulting with the larger aircraft (AA) causes considerably more delay. (The difference between conditions No. 1 and 2, and 6A and 6B.) For the existing airport this is $2,580,000 and the improved airport $2,156,000 per year.

. To provide maximum noise relief is expensive in delay to the passenger. For the improved airport, this is about 110,000 additional hours per year (No. 6 and 6B, but converted to passenger hours). For the existing

compared to the improved, (No. 5 and 6) this is about 470,000 hours per year.

. To provide maximum noise relief is expensive in delay and in operating cost to the airlines and other aircraft operators. For the aircraft operators on the existing airport (No. 2 and 5) this is $1,973,000. For the aircraft operators on the expanded airport (No. 6 and 6B) this is $556,000.

. There is a major saving to the aircraft operators for building the new runway 15L-33R while achieving a greater percentage of overwater operations. This is approximately $2,350,000 per year (5 and 6) to achieve maximum overwater use.

To understand the meaning of this delay to the service being rendered, Exhibit A-18 shows an example of the delay by hour over 24 hours. First, the lower curve shows that for both the existing airport (condition No. 1) and the airport with 15-33 added (condition No. 6A), when a most efficient runway combination is in use, there is not a lot of difference in delay. However, when single runway use is needed as it is with the existing airport for six percent of the time, or about 20 days of the year, the delay is very high - an average of 46 minutes in the morning and 41 minutes in the afternoon. The same condition occurs only seven days a year, one-third as much when 15L-33R has been added. Thus, the air traveler can expect lower delay and greater reliability of service with addition of a new runway. Exhibit A-19 depicts the same information during IFR conditions. Here, also, because a single runway will be used much less after 15L-33R is added, the public will have a lower delay for a greater percentage of the

EXHIBIT A-18

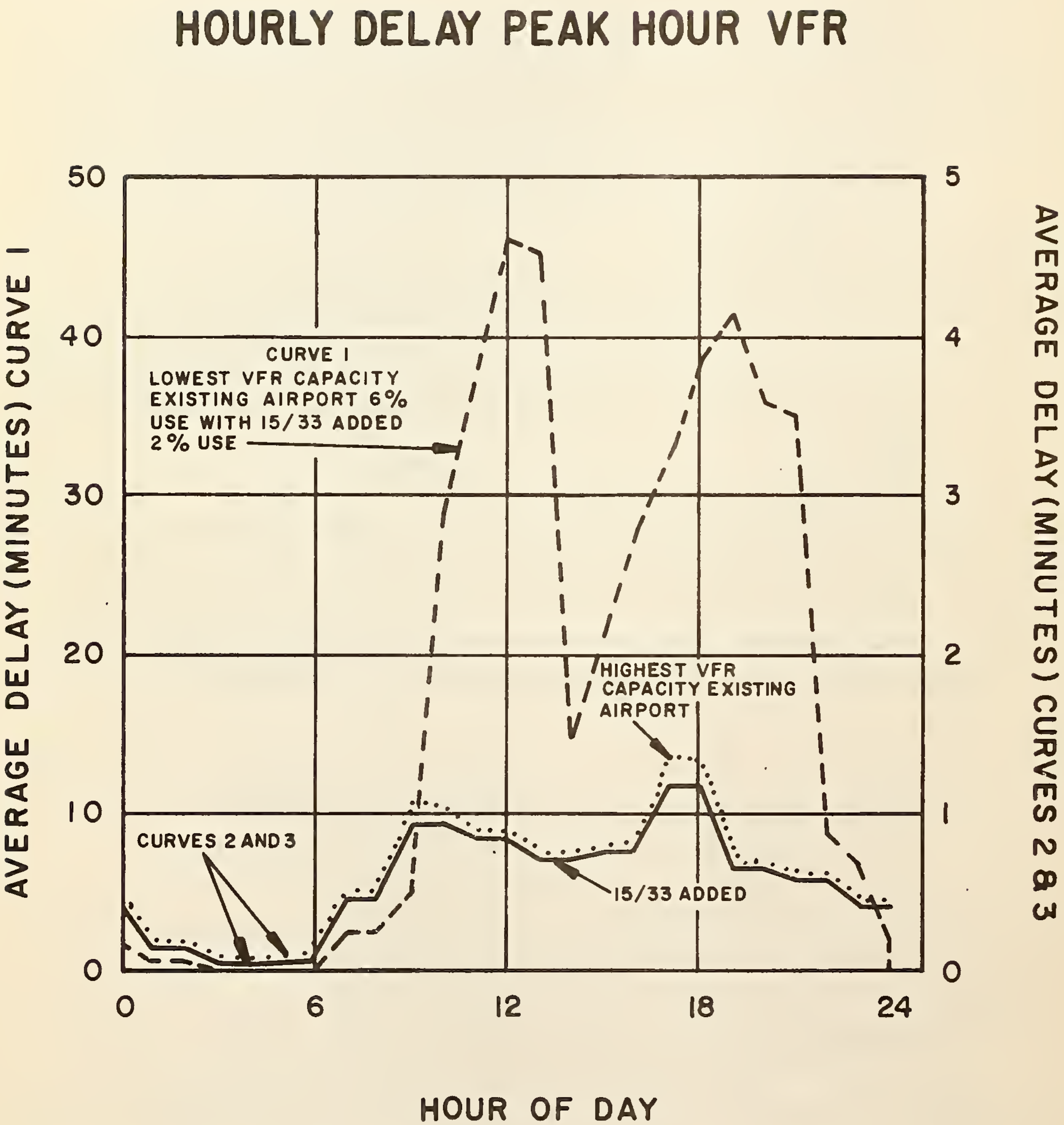
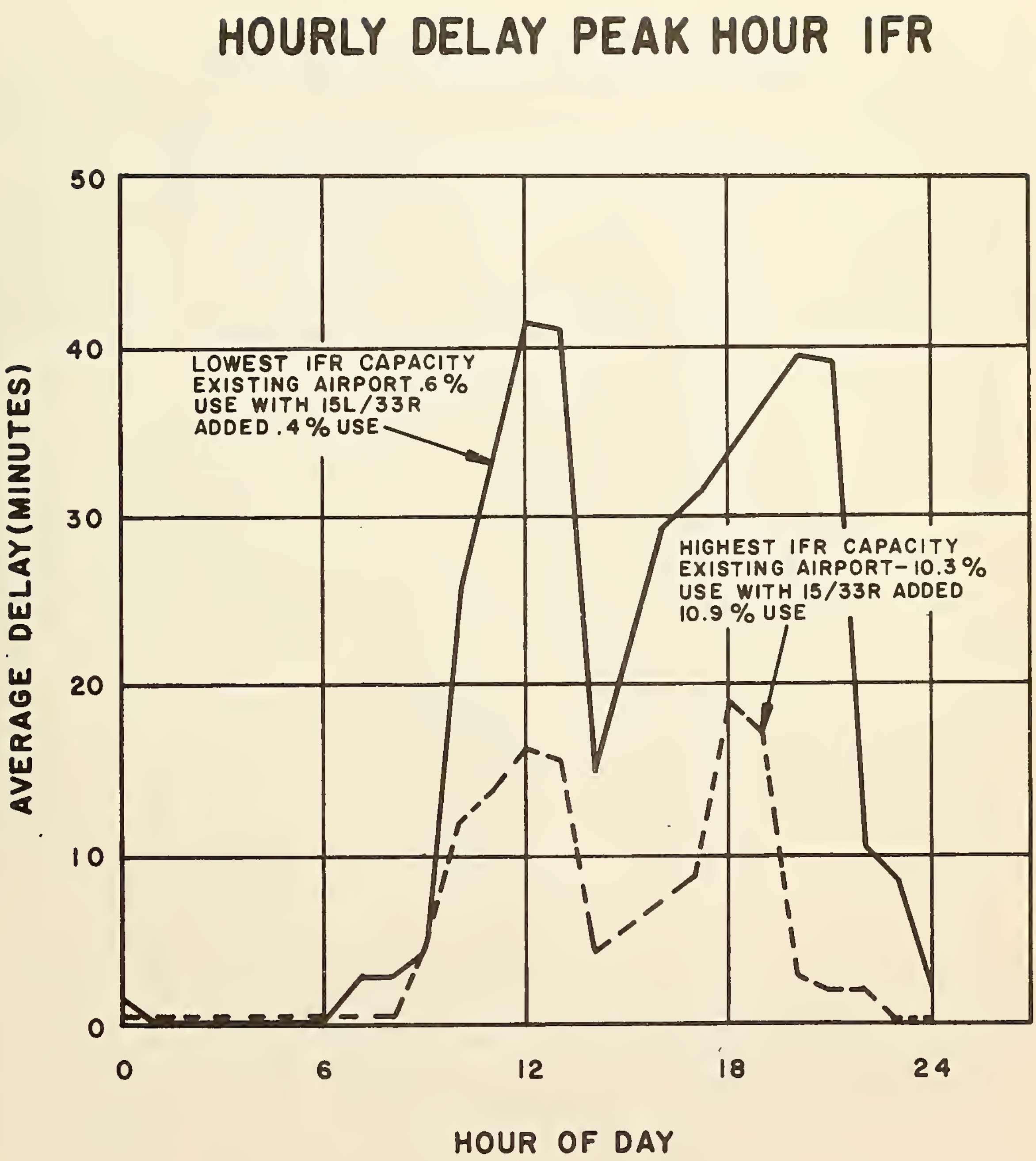

HOURLY DELAY PEAK HOUR VFR
AVERAGE DELAY (MINUTES) CURVE I
AVERAGE DELAY (MINUTES) CURVES 2 & 3
CURVE I
LOWEST VFR CAPACITY
EXISTING AIRPORT 6%
USE WITH 15/33 ADDED
2% USE
HIGHEST VFR
CAPACITY EXISTING
AIRPORT
CURVES 2 AND 3
15/33 ADDED
0
10
20
30
40
50
0
1
2
3
4
5
0
6
12
18
24
HOUR OF DAY

EXHIBIT A-19


HOURLY DELAY PEAK HOUR IFR
AVERAGE DELAY (MINUTES)
50
40
30
20
10
0
LOWEST IFR CAPACITY
EXISTING AIRPORT .6 %
USE WITH 15L/33R
ADDED .4 % USE
HIGHEST IFR CAPACITY
EXISTING AIRPORT-10.3 %
USE WITH 15/33R ADDED
10.9 % USE
0
6
12
18
24
HOUR OF DAY

time, and thus more reliable service.

To summarize the capacity and delay analysis, it is important to the operation of the airport that its capacity be increased in order that it can more satisfactorily handle the increased demand at the airport and provide maximum overwater operations. The addition of runway 15L-33R will provide a substantially improved service to the air traveler by providing service at a lower delay level, and therefore, a more reliable operation, and at the same time, permit achieving a greater degree of overwater operations.

9. THE ADDITION OF A 15-33 STOL RUNWAY CAN PROVIDE ADDITIONAL CAPACITY FOR STOL AND LIGHT AIRCRAFT

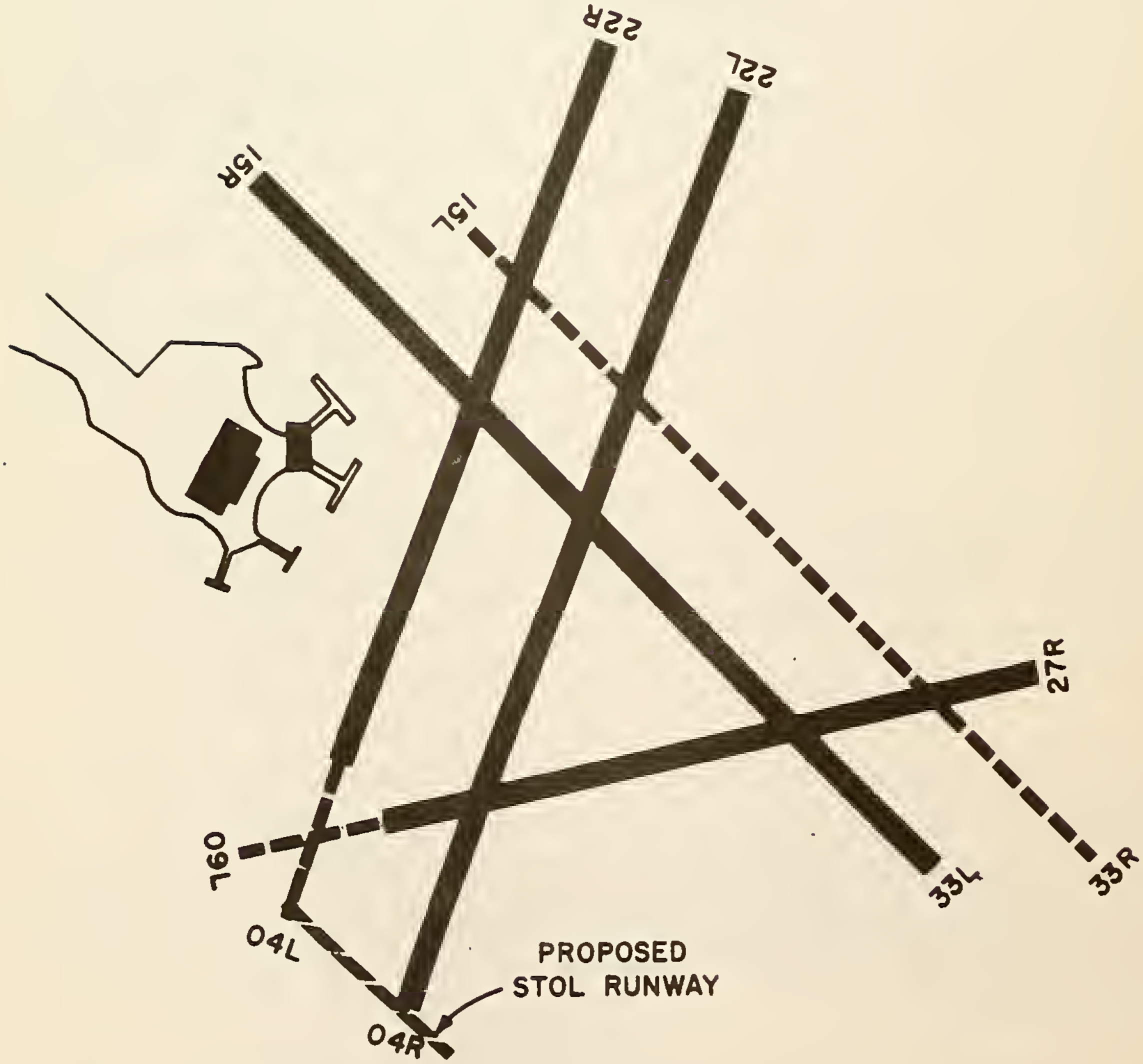
****

Another way of increasing capacity in the future for Boston-Logan International Airport is to add runways to accommodate short take-off and landing (STOL) aircraft. Exhibit A-20 indicates the suggested location of a STOL runway to parallel the 15-33 runways. The separation of the STOL runway from the parallel CTOL runways is adequate for future simultaneous IFR approaches to both runways. The operation of STOL aircraft on this runway would limit the flexibility of use of the conventional (CTOL) aircraft runways because only parallel runways could be used. However, to achieve the revised preferential runway use and accommodate independent operation of STOL aircraft is considered practical,for generally the STOL aircraft because of its short runway needs could use runways not used by CTOL aircraft in the preferential program. There would be a substantial overall increase in airport capacity. This increase could be on the order of 235,000 movements if a full STOL runway system were provided. The STOL runways would also be used for small CTOL aircraft, but would increase air carrier capacity by about 150,000 movements, if half the capacity is assigned for air carrier use.

While STOL may ultimately extend Logan's capacity, there is little likelihood that a viable STOL air transportation system, including an economic STOL aircraft and a network of STOL ports could or will be developed and in substantial operation before existing Logan Airport capacity will be greatly exceeded and cause intolerable delay levels.

EXHIBIT A-20

BOSTON LOGAN AIRPORT SHOWING STOL RUNWAY



APPENDIX A-1

RUNWAY USE ANALYSIS STATISTICS

****

Four runway use analyses are discussed in the text. Key statistical details are presented herein.

The 10 year historical summary is based on records of the Massachusetts Port Authority during the years 1959 through 1968. The three other summaries are derived from a five year historical record, 1960 through 1964.

These statistics are also the basis for the runway use in the noise analysis contained in a related appendix.

EXISTING AIRPORT

Runway Use Summary
Airport Operated to Attain
Maximum Capacity, Minimum Delay

	04R	04L	22R	22L	15R	33L	09	27	
A	7.10	25.64	-	43.77	1.25	9.75	.71	1.78	100.0
D	35.64	7.10	43.77	-	.18	3.61	1.78	7.92	100.0

EXISTING AIRPORT

10 Year Historical Summary of Runway Use

	04R	04L	22R	22L	15R	15L	33R	33L	09	27	
A	18.4	9.2	2.9	24.0	8.9	.4	1.0	24.1	2.0	9.1	100.0
D	14.9	2.8	20.8	4.9	14.5	.1	.1	24.4	11.3	6.2	100.0

A = Arrivals
D = Departures

EXISTING AIRPORT

Runway Use Summary
Seasons Weighted
Noise Abatement Alternate No.1

Day		04R	04L	22R	22L	15R	33L	09	27	
May-Sept.	A	4.42	6.37	-	14.25	.67	10.33	.11	1.32	
Oct.-Apr.	A	3.36	9.26	-	13.39	.84	22.43	.63	2.68	
Total		7.78	15.63	-	27.64	1.51	32.76	.74	4.00	90.06
May-Sept.	D	8.78	-	12.70	-	10.41	.54	3.54	1.88	
Oct.-Apr.	D	14.75	-	14.10	-	8.06	3.37	6.21	6.12	
Total		23.53	-	26.80	-	18.47	3.91	9.75	8.00	90.46
Nite										
May-Sept.	A	.79	.02	-	1.17	.07	1.76	.01	.20	
Oct.-Mar.	A	.59	.06	-	1.00	.09	3.41	.07	.36	
Total		1.38	.08	-	2.17	.16	5.17	.08	.56	9.60
May-Sept.	D	.44	-	.90	-	2.02	.06	.40	.20	
Oct.-Apr.	D	1.02	-	1.07	-	1.72	.36	.70	.65	
Total		1.46	-	1.97	-	3.74	.42	1.10	.85	9.54

A = Arrivals
D = Departures

IMPROVED AIRPORT WITH 15L/33R

Runway Use Summary
Seasons Weighted
Maximum Noise Abatement

Day		04R	04L	22R	22L	15R	15L	33R	33L	09	27	
May-Sept.	A	4.51	1.77	-	10.94	-	2.48	5.81	10.72	.12	1.52	
Oct.-Apr.	A	3.66	1.77	-	9.33	-	2.15	14.31	17.82	.63	2.91	
Total		8.17	3.54	-	20.27	-	4.63	20.12	28.54	.75	4.43	90.45
May-Sept.	D	4.20	-	9.56	-	.22	12.72	-	4.75	4.92	1.50	
Oct.-Apr.	D	8.16	-	10.79	-	.33	9.71	-	10.94	7.75	4.89	
Total		12.36	-	20.35	-	.55	22.43	-	15.69	12.67	6.39	90.44
Nite												
May-Sept.	A	.78	.02	-	1.17	-	.07	.03	1.54	.01	.20	
Oct.-Apr	A	.59	.05	-	1.00	-	.09	.84	2.56	.07	.36	
Total		1.37	.07	-	2.17	-	.16	.87	4.10	.08	.56	9.38
May-Sept.	D	.44	-	.90	-	.18	1.83	-	.06	.40	.20	
Oct.-Apr	D	1.02	-	1.13	-	.32	1.40	-	.36	.70	.66	
Total		1.46	-	2.03	-	.50	3.23	-	.42	1.10	.86	9.60

A = Arrivals
D = Departures

APPENDIX B

EVALUATION OF AIRCRAFT NOISE IN THE VICINITY OF BOSTON-LOGAN INTERNATIONAL AIRPORT

Report No. 2150

May 1971

Submitted to:

Landrum and Brown Inc.
1200 Central Trust Tower
Cincinnati, Ohio 45202

I. INTRODUCTION

The operation of aircraft in and around an airport can produce considerable noise exposure in the communities near the airport. In order to evaluate and minimize the consequences of such exposure, the possible changes in noise exposure associated with significant airport operational changes must be examined objectively.

The Massachusetts Port Authority, operator of the Boston-Logan International Airport, has proposed the construction of a new parallel runway (Runway 15L-33R), and the extension of Runway 4L and Runway 9. The Port Authority has retained a team of consultants headed by the firm of Landrum and Brown, Inc., to study the environmental impact of the proposed runway and improvements. As a part of this study, Bolt Beranek and Newman Inc. (BBN) has described the noise exposure for six conditions, one condition with 1970 aircraft traffic, and five conditions considering different methods of operating the airport with projected 1975 aircraft traffic. This report presents the results of the BBN study, which was conducted during May 1971.

The noise exposure associated with Boston-Logan International Airport operations has been described in two previous reports:

1. "Aircraft Noise and Airport Neighbors: A Study of Logan International Airport", DOT/HUD IANAP-70-1, March 1970; and revision, March 1971.

2. "Noise Exposure Forecast Contours for 1967, 1970, and 1975 Operations at Selected Airports," FAA-NO-70-8, September 1970.

The descriptions of noise exposure in both reports were based on operational information and forecasts developed by the Federal Aviation Administration in 1968. The differences between the descriptions of noise exposure in the two reports are due primarily to a BBN misinterpretation in the March 1970 report. The fact that this error was corrected in the September 1970 report but not in the March 1970 report was detected in March 1971, at which time the revision to the March 1970 report was prepared and issued. As pointed out in the revision, the land areas and populations associated with the noise description in the September 1970 report are in the range of 53% to 65% of (or 47% to 35% lower than) the corresponding values in the March 1970 report. Certain refinements in the methodology also contributed to the differences in the descriptions of noise exposure given in these two reports.

The present report represents a third study of the Boston-Logan International Airport noise exposure. A significant way in which this study differs from the two previous studies is in the refined and updated operational information and forecasts used as inputs to the study. This study utilizes operational information and forecasts developed in 1971 for the Massachusetts Port Authority by the consulting firms of Landrum and Brown, Inc., and R. Dixon Speas Associates, Inc. Because of the importance of the forecasts in determining the noise exposure descriptions, Chapters 1 and 2 of the consultant's report* presents a summary of the development of the forecasts, and a comparison with previous operational information and forecasts.

*Environmental Impact Study--Boston-Logan International Airport, 1971.

The two previous studies and this study describe the airport-community noise situation in terms of Noise Exposure Forecast (NEF) contours. The contour values increase as noise exposure increases. A comparison of the shapes and sizes of a given contour for two different conditions provides an indication of the relative increase or decrease of the noise exposure between the two conditions.

Section II of this report presents the Noise Exposure Forecast contours obtained in this study. The results show that the size of the 1975 contours can be reduced significantly, so that the values of land areas and populations for 1975 can be in the range of 36% to 73% of (or 64% to 27% lower than) the corresponding values for 1970. Furthermore, the results show that the values of land areas and populations for 1975 can be in the range of 21% to 40% of (or 79% to 60% lower than) the corresponding values for 1975 as reported in the earlier studies (see March 1971 revision). These reductions are associated in large part with the use of updated operational information, the greater use of over-water flight paths, and the shifting of some traffic from nighttime to daytime.

The Noise Exposure Forecast contours, which are intended to display the exposure over the entire airport vicinity, show no significant changes associated with the extension of Runway 9 to the west 1900 ft. This extension can, however, provide some reduction in the noise levels experienced by residents in the Point Shirley area of Winthrop, because departing aircraft can cross the areas at altitudes up to several hundred feet higher than at present.

II. NOISE EXPOSURE FORECASTS

Six airport conditions have been considered in this study (see Table I). The designations of these conditions follow the nomenclature established in the consultant's report. The first condition, designated "1970", is based on aircraft traffic and runway utilization information representing actual airport experience during 1970. The second condition, designated "1975 - Maximum Capacity", is based on projected 1975 aircraft traffic and a runway utilization that improves capacity by making increased use of the existing parallel runways (Runway 4-22). The third condition, designated "1975-Historic", is based on projected 1975 aircraft traffic and the 1970 runway utilization information. Thus, this condition corresponds to the situation that would exist in 1975 if the traffic increased as forecasted but the airport were operated exactly as in 1970.

The fourth and fifth conditions, designated "1975 - Maximum Noise Abatement and Existing Airport - Alternates 1 and 2," are based on projected 1975 aircraft traffic and runway utilizations that reduce the use of over-land flight paths and increase the use of over-water flight paths. The sixth condition, designated "1975 - Maximum Noise Abatement and Improved Airport", is based on projected 1975 aircraft traffic and runway utilization information assuming the operation of the new parallel runway (Runway 15L-33R), and reduced use of over-land flight paths. This condition also includes provision for shifting some nighttime activity to daytime, because of the greater capacity afforded by the new runway.

Tables I through X and Figure 1 summarize the operational information utilized in the construction of the contours.

The Noise Exposure Forecast contours were computed using the same procedure as was used in the September, 1970 report referred to on page 1, except that a correction was made for the reduction of thrust with altitude. The nature of this correction is as follows: as an aircraft gains altitude, the decrease in net thrust results in lower noise radiation. This decrease in noise level with altitude can be roughly approximated by a density- and temperature-dependent correction, of the order of -2 EPNdB per 10,000 feet of altitude above 1000 ft. The use of this correction should provide a more realistic description of the noise observed on the ground resulting from aircraft at high altitudes.

Figures 2 through 7 show the NEF contours for the airport configuration and anticipated aircraft activity for the six conditions studied. Each of the figures shows contours for three NEF values, 30, 35, and 40. Points lying on the same contour experience approximately the same total noise exposure.

As part of the noise abatement program at Logan Airport, aircraft taking off from Runway 22R make a left turn after takeoff, following flight path 22R-B (Fig. 1). As seen in the contours, the effect of this procedure is beneficial, moving a portion of the contours in the southwest section away from populated areas.

The contours of Figs. 2 through 7 are intended to represent long-term average pictures of the noise exposure. Therefore, the operational information utilized in developing the contours is based on conditions averaged over an entire year. Noise measurements made at any one time (say, over a period of a few days) may be thought of as representing a "snapshot" of the situation at that time, rather than the long-term average of the NEF contours. Thus, the year-average picture of the NEF contours cannot be compared directly with short-term "snapshot" noise measurements, although such noise measurements do serve as the starting point of the description of noise exposure.

Table XI presents figures for land area and population contained within the NEF 30 and 40 contours, for the six conditions studied, and figures for schools and dwelling units for four of the conditions studied. Area, dwelling unit, and 1963 population information was provided by the Metropolitan Area Planning Council for fundamental areal units called "traffic zones". The fraction of each traffic zone lying within a given NEF contour was identified. Traffic zone population and dwelling unit information for 1963 was scaled to 1970 and 1975 conditions on the basis of municipal population estimates.

For schools within the NEF 30 contours, the school information was obtained by the same general procedure as was used for the land area, population, and dwelling unit information, that is, in terms of traffic zones. For schools within the more critical NEF 40 contours, greater precision was achieved by identifying each school location individually rather than by assigning each school to a traffic zone.

Several factors account for the difference among the NEF contours in Figs. 2 through 7. The principal factors include: (1) the increase in number of operations, which tends to increase the size of a given contour; (2) the increased use of the newer and quieter high-bypass-ratio (HBPR) turbofan aircraft, which tends to decrease the size of a given contour; (3) the increased use of over-water flight paths, which tends to reduce the land area and population within a given contour; and (4) the shifting of nighttime activity to daytime, which tends to reduce the size of a given contour. For example, comparison of Figs. 2 and 4, involving the same runway utilization and day-night distribution, shows that the unfavorable effect associated with the anticipated increase in number of operations between 1970 and 1975 is essentially balanced by the favorable effect associated with the increased use of HBPR aircraft. In addition, Figs. 5, 6, and 7 show that the increased use of over-water flight paths and the shifting of nighttime activity to daytime can reduce the land areas and populations within the 1975 contours. Thus, the values of land areas and populations for the 1975 - Improved Airport Configuration (Condition 6) are in the range of 36% to 73% of the corresponding values in 1970.

The interpretation of the NEF contours in any specific situation may involve considerable flexibility, depending on the details of the situation. The following factors are among those that must be considered:

a) Previous community experience. One may utilize past experience and take into consideration known responses in previously developed areas with similar noise exposures.

b) Local building construction, particularly as influenced by considerations of climate. In cooler portions of the country, wall and roof constructions are likely to be slightly heavier and houses more tightly constructed, thus reducing the number of noise leakage paths. In addition, windows are typically kept closed for a larger portion of the year. On this basis one might accept a somewhat higher NEF value as acceptable for indoor activities in cooler portions of the country than would be acceptable for similar activities in warmer portions of the country.

c) Time period of land use activities. The NEF contours are constructed on the basis of both daytime and nighttime aircraft operations. This procedure is generally appropriate for residential land use considerations, but may lead to overestimation of NEF values for those work activities or land uses that are confined to daytime hours only. Thus, for such activities or land uses, it may be desirable to adjust the NEF values to define the noise exposure for daytime aircraft operations only.

It is important to point out that when one wishes to determine the specific noise insulation required for a given work activity, definition of the noise environment in terms of the NEF value alone is insufficient. One must supplement that NEF value by more detailed specification of the magnitude of the aircraft noise intrusions. In general, this would begin with determining some single-number description of the noise levels (such as Perceived Noise Level or A-Weighted Sound Level) for the noise intrusions. This must usually be followed by more detailed descriptions of the noise events, for example, in terms of octave band noise spectra and signal durations, as well as knowledge of the background noise levels and interior noise criteria. These steps follow well-defined noise control procedures.

TABLE I

CONDITIONS STUDIED AT BOSTON - LOGAN INTERNATIONAL AIRPORT

CONDITION	DESIGNATION	AIRPORT CONFIGURATION	TRAFFIC PROJECTION	RUNWAY UTILIZATION	NEF CONTOURS
1	1970	Existing	Table II	Table VI	Fig. 2
2	1975 - Maximum Capacity	Existing	Table III	Table VII	Fig. 3
3	1975 - Historic	Existing	Table III	Table VI	Fig. 4
4	1975 - Maximum Noise Abatement and Existing Airport - Alternate 1	Existing	Table III	Table VIII	Fig. 5
5	1975 - Maximum Noise Abatement and Existing Airport - Alternate 2	Existing	Table IV	Table IX	Fig. 6
6	1975 - Maximum Noise Abatement and Improved Airport	Improved	Table V	Table X	Fig. 7

TABLE II

OPERATIONAL INFORMATION FOR Logan YEAR 1970

AIRCRAFT TYPE		LANDINGS	TAKEOFFS - STAGE LENGTHS IN NAUTICAL MILES						
			0-500	501 - 1000	1001 - 1500	1501 - 2500	2501 - 3500	3501 - 4500	4501 and longer
1. 4 - Engine Turbojet	Day	27.571	1.791	10.752	.896	2.912	6.048		
	Night	2.564	2.243	2.863	0.0	0.0	2.630		
2. 4 - Engine Turbofan	Day	26.655	4.853	9.706	1.213	1.820	12.738		
	Night	8.847	3.207	1.293	0.0	0.0	.672		
3. 4 - Engine "Stretch Fan"	Day	0.0	0.0	0.0	0.0	0.0	0.0		
	Night	0.0	0.0	0.0	0.0	C.0	0.0		
4. 3 - Engine Turbofan	Day	26.223	20.249	5.138	4.231	.605	0.0		
	Night	8.217	2.109	2.108	0.0	0.0	0.0		
5. 3 - Engine "Stretch Fan"	Day	36.258	28.508	5.702	6.515	0.0	0.0		
	Night	6.620	2.153	0.0	0.0	0.0	0.0		
6. 2 - Engine Turbofan	Day	114.035	118.144	2.461	2.461	0.0	0.0		
	Night	14.311	5.280	0.0	0.0	0.0	0.0		
7. 4 - Engine HBPR Fan	Day	1.033	0.0	0.0	0.0	0.0	1.033		
	Night	0.0	0.0	0.0	0.0	0.0	0.0		
8. 2, 3 - Engine HBPR Fan	Day	0.0	0.0	0.0	0.0	0.0	0.0		
	Night	0.0	0.0	0.0	0.0	0.0	0.0		
9. Boeing 2707 - 300	Day	0.0	0.0	0.0	0.0	0.0	0.0		
	Night	0.0	0.0	0.0	0.0	0.0	0.0		
10. Cen. Aviation Jet	Day	4.568	4.669	0.0	0.0	0.0	0.0		
	Night	.237	.136	0.0	0.0	0.0	0.0		
11. 4 - Engine Propeller	Day	4.867	4.355	0.0	0.0	0.0	0.0		
	Night	1.257	1.769	0.0	0.0	0.0	0.0		
12. 2 - Engine Prop >12,500 lb	Day	11.058	11.126	0.0	0.0	0.0	0.0		
	Night	.182	.114	0.0	0.0	0.0	0.0		
13. 2 - Engine Prop <12,500 lb	Day								
	Night								
	Day								
	Night								
	Day								
	Night								

TABLE III

OPERATIONAL INFORMATION FOR Logan (Existing-1) YEAR 1975

AIRCRAFT TYPE			LANDINGS	TAKEOFFS - STAGE LENGTHS IN NAUTICAL MILES 0-500	501 - 1000	1001 - 1500	1501 - 2500	2501 - 3500	3501 - 4500	4501 and longer
1.	4 - Engine Turbojet	Day	12.262	.769	4.615	.385	1.250	2.596		
		Night	1.218	1.121	1.430	0.0	0.0	1.314		
2.	4 - Engine Turbofan	Day	25.157	4.445	8.889	1.111	1.667	11.667		
		Night	8.543	3.671	1.480	0.0	0.0	.770		
3.	4 - Engine "Stretch Fan"	Day	0.0	0.0	0.0	0.0	0.0	0.0		
		Night	0.0	0.0	0.0	0.0	0.0	0.0		
4.	3 - Engine Turbofan	Day	45.922	34.446	8.740	7.198	1.028	0.0		
		Night	14.738	4.624	4.624	0.0	0.0	0.0		
5.	3 - Engine "Stretch Fan"	Day	28.333	21.698	4.340	4.959	0.0	0.0		
		Night	5.367	2.703	0.0	0.0	0.0	0.0		
6.	2 - Engine Turbafan	Day	113.127	114.192	2.379	2.379	0.0	0.0		
		Night	14.933	9.110	0.0	0.0	0.0	0.0		
7.	4 - Engine HBPR Fan	Day	11.593	1.333	4.445	.445	1.111	3.778		
		Night	1.887	1.066	.734	0.0	0.0	.568		
8.	2, 3 - Engine HBPR Fan	Day	40.566	25.155	5.805	5.805	2.768	1.945		
		Night	6.614	3.833	1.277	0.0	0.0	.592		
9.	Boeing 2707 - 300	Day	0.0	0.0	0.0	0.0	0.0	0.0		
		Night	0.0	0.0	0.0	0.0	0.0	0.0		
10.	Gen. Aviation Jet	Day	4.973	5.489	0.0	0.0	0.0	0.0		
		Night	1.033	.517	0.0	0.0	0.0	0.0		
11.	4 - Engine Prapeller	Day	1.498	1.598	0.0	0.0	0.0	0.0		
		Night	.310	.210	0.0	0.0	0.0	0.0		
12.	2 - Engine Prap >12,500 lb	Day	6.877	7.341	0.0	0.0	0.0	0.0		
		Night	1.428	.964	0.0	0.0	0.0	0.0		
13.	2 - Engine Prop <12,500 lb	Day								
		Night								
		Day								
		Night								
		Day								
		Night								

TABLE IV

OPERATIONAL INFORMATION FOR LOGAN (Existing-2) YEAR 1975

AIRCRAFT TYPE			LANDINGS	TAKEOFFS - STAGE LENGTHS IN NAUTICAL MILES						
				0-500	501 - 1000	1001 - 1500	1501 - 2500	2501 - 3500	3501 - 4500	4501 and longer
1.	4 - Engine Turbojet	Day	11.858	.712	4.434	.373	1.212	2.480		
		Night	1.622	1.178	1.611	.012	.038	1.430		
2.	4 - Engine Turbofan	Day	24.135	4.202	8.578	1.078	1.617	11.293		
		Night	9.565	3.914	1.791	.033	.050	1.144		
3.	4 - Engine "Stretch Fan"	Day								
		Night								
4.	3 - Engine Turbofan	Day	44.102	33.274	8.339	6.982	.997	0.0		
		Night	16.558	5.796	5.025	.216	.031	0.0		
5.	3 - Engine "Stretch Fan"	Day	27.322	20.966	4.210	4.810	0.0	0.0		
		Night	6.378	3.435	.130	.149	0.0	0.0		
6.	2 - Engine Turbofan	Day	109.267	110.492	2.308	2.308	0.0	0.0		
		Night	18.793	12.810	.071	.071	0.0	0.0		
7.	4 - Engine HBPR Fan	Day	11.189	1.261	4.290	.431	1.078	3.648		
		Night	2.291	1.138	.889	.014	.033	.698		
8.	2, 3 - Engine HBPR Fan	Day	39.151	24.285	5.593	5.631	2.685	1.869		
		Night	8.029	4.703	1.489	.174	.083	.668		
9.	Boeing 2707 - 300	Day								
		Night								
10.	Gen. Aviation Jet	Day	4.793	4.793						
		Night	1.213	1.213						
11.	4 - Engine Propeller	Day	1.444	1.444						
		Night	.364	.364						
12.	2 - Engine Prop >12,500 lb	Day	6.628	6.628						
		Night	1.677	1.677						
13.	2 - Engine Prop <12,500 lb	Day								
		Night								
		Day								
		Night								
		Day								
		Night								

TABLE V

OPERATIONAL INFORMATION FOR Logan (Improved) YEAR 1975

AIRCRAFT TYPE			LANDINGS	TAKEOFFS - STAGE LENGTHS IN NAUTICAL MILES						
				0-500	501 - 1000	1001 - 1500	1501 - 2500	2501 - 3500	3501 - 4500	4501 and longer
1.	4 - Engine Turbojet	Day	12.641	.802	4.809	.401	1.302	2.705		
		Night	.840	1.004	1.281	0.0	0.0	1.176		
2.	4 - Engine Turbofan	Day	25.935	4.606	9.213	1.152	1.727	12.092		
		Night	7.765	3.044	1.228	0.0	0.0	.638		
3.	4 - Engine "Stretch Fan"	Day	0.0	0.0	0.0	0.0	0.0	0.0		
		Night	0.0	0.0	0.0	0.0	0.0	0.0		
4.	3 - Engine Turbofan	Day	47.342	35.665	9.049	7.453	1.065	0.0		
		Night	13.318	3.714	3.714	0.0	0.0	0.0		
5.	3 - Engine "Stretch Fan"	Day	29.209	22.406	4.481	5.121	0.0	0.0		
		Night	4.491	1.692	0.0	0.0	0.0	0.0		
6.	2 - Engine Turbofan	Day	116.626	117.880	2.456	2.456	0.0	0.0		
		Night	11.434	5.268	0.0	0.0	0.0	0.0		
7.	4 - Engine HBPR Fan	Day	11.952	1.382	4.606	.461	1.152	3.915		
		Night	1.528	.884	.609	0.0	0.0	.471		
8.	2, 3 - Engine HBPR Fan	Day	41.821	26.009	6.002	6.002	2.864	2.015		
		Night	5.359	2.847	.949	0.0	0.0	.492		
9.	Boeing 2707 - 300	Day	0.0	0.0	0.0	0.0	0.0	0.0		
		Night	0.0	0.0	0.0	0.0	0.0	0.0		
10.	Gen. Aviation Jet	Day	5.127	5.489	0.0	0.0	0.0	0.0		
		Night	.879	.517	0.0	0.0	0.0	0.0		
11.	4 - Engine Propeller	Day	1.544	1.652	0.0	0.0	0.0	0.0		
		Night	.264	.156	0.0	0.0	0.0	0.0		
12.	2 - Engine Prop >12,500 lb	Day	7.090	7.590	0.0	0.0	0.0	0.0		
		Night	1.215	.715	0.0	0.0	0.0	0.0		
13.	2 - Engine Prop <12,500 lb	Day								
		Night								
		Day								
		Night								
		Day								
		Night								

TABLE VI

RUNWAY UTILIZATION PERCENTAGES

Historic (1970 and 1975)

Flight Track	Takeoff		Landing	
	Day	Night	Day	Night
04L-A	2.8	2.8	2.9	2.9
04R-A	14.9	14.9	24.0	24.0
09-A	11.3	11.3	9.1	9.1
15L-A	0.0	0.0	0.0	0.0
15R-A	14.6	14.6	25.1	25.1
22L-A	4.9	4.9	18.4	18.4
22R-A	0.0	0.0	9.2	9.2
22R-B	20.8	20.8	0.0	0.0
27-A	6.2	6.2	2.0	2.0
33L-A	24.5	24.5	9.3	9.3
33R-A	0.0	0.0	0.0	0.0
33L, R-B	24.5	24.5	9.3	9.3

*See Figure 1 for a description of flight track designations.

TABLE VII

RUNWAY UTILIZATION PERCENTAGES

Maximum Capacity (1975)

Flight Track*	Takeoff		Landing	
	Day	Night	Day	Night
04L-A	0.0	0.0	0.0	0.0
04R-A	42.74	42.74	43.77	43.77
09-A	1.78	1.78	1.78	1.78
15L-A	0.0	0.0	0.0	0.0
15R-A	0.18	0.18	9.75	9.75
22L-A	0.0	0.0	0.0	0.0
22R-A	0.0	0.0	42.74	42.74
22R-B	43.77	43.77	0.0	0.0
27-A	7.92	7.92	0.71	0.71
33L-A	3.61	3.61	1.25	1.25
33R-A	0.0	0.0	0.0	0.0
33L, R-B	3.61	3.61	1.25	1.25

*See Figure 1 for a description of flight track designations.

TABLE VIII

RUNWAY UTILIZATION PERCENTAGES

Maximum Noise Abatement and Existing Airport-Alternate 1 (1975)

Flight Track*	Takeoff		Landing	
	Day	Night	Day	Night
04L-A	0.0	0.0	0.0	0.0
04R-A	26.01	15.304	30.69	22.605
09-A	10.78	11.53	4.44	5.83
15L-A	0.0	0.0	0.0	0.0
15R-A	20.42	39.203	36.38	53.855
22L-A	0.0	0.0	8.64	14.38
22R-A	0.0	0.0	17.35	0.83
22R-B	29.63	20.65	0.0	0.0
27-A	8.84	8.91	0.82	0.83
33L-A	4.32	4.403	1.68	1.67
33R-A	0.0	0.0	0.0	0.0
33L, R-B	4.32	4.403	1.68	1.67

*See Figure 1 for a description of flight track designations.

TABLE IX

RUNWAY UTILIZATION PERCENTAGES

Maximum Noise Abatement and Existing Airport-Alternate 2 (1975)

Flight Track*	Takeoff		Landing	
	Day	Night	Day	Night
04L-A	0.0	0.0	0.0	0.0
04R-A	13.67	15.21	22.41	23.13
09-A	14.01	11.46	4.90	5.97
15L-A	0.0	0.0	0.0	0.0
15R-A	25.41	38.855	53.80	52.98
22L-A	0.0	0.0	9.03	14.61
22R-A	0.0	0.0	3.91	0.75
22R-B	22.50	21.145	0.0	0.0
27-A	7.06	8.96	0.83	0.85
33L-A	17.35	4.37	5.12	1.71
33R-A	0.0	0.0	0.0	0.0
33L, R-B	17.35	4.37	5.12	1.71

*See Figure 1 for a description of flight track designations.

TABLE X

RUNWAY UTILIZATION PERCENTAGES

Maximum Noise Abatement and Improved Airport (1975)

Flight Track*	Takeoff		Landing	
	Day	Night	Day	Night
04L-A	0.0	0.0	0.0	0.0
04R-A	13.67	15.21	22.41	23.13
09-A	14.01	11.46	4.90	5.97
15L-A	24.80	33.645	22.25	9.27
15R-A	0.61	5.21	31.55	43.71
22L-A	0.0	0.0	9.03	14.61
22R-A	0.0	0.0	3.91	0.75
22R-B	22.50	21.145	0.0	0.0
27-A	7.06	8.96	0.83	0.85
33L-A	17.35	4.37	0.0	0.0
33R-A	0.0	0.0	5.12	1.71
33L, R-B	17.35	4.37	5.12	1.71

* See Figure 1 for a description of flight track designations.

TABLE XI

LAND AREAS, POPULATIONS, SCHOOLS, AND DWELLING UNITS CONTAINED WITH THE NOISE EXPOSURE FORECAST CONTOURS

SECTOR*	ITEM	NEF 30 CONDITION 1	2	3	4	5	6
Southwest	Land Area (Thousand Acres)	2.0	4.8	2.2	2.0	1.8	1.6
	Population (Thousands)	12.2	47.5	12.1	9.3	10.8	8.6
	Schools	6	22	6			4
	Dwelling Units (Thousands)	3.4	13.4	3.4			2.4
Northeast	Land Area (Thousand Acres)	3.4	6.8	3.5	2.5	3.2	3.0
	Population (Thousands)	30.0	64.0	31.1	23.3	30.9	24.6
	Schools	19	37	19			16
	Dwelling Units (Thousands)	11.3	22.8	11.5			9.6
Northwest	Land Area (Thousand Acres)	5.0	1.2	5.5	1.5	2.6	2.0
	Population (Thousands	64.5	17.1	70.9	21.6	29.7	25.5
	Schools	37	11	41			17
	Dwelling Units (Thousands)	19.3	5.0	21.2			7.5

TABLE XI (cont.)

SECTOR*	ITEM	NEF 30 CONDITION 1	2	3	4	5	6
Southeast	Land Area (Thousand Acres)	0.4	0.4	0.4	0.7	0.6	0.6
	Population (Thousands)	0.4	0.4	0.4	3.0	1.9	3.7
	Schools	0	0	0			1
	Dwelling Units (Thousands)	0.1	0.1	0.1			1.1
West	Land Area (Thousand Acres)	0.8	1.2	1.1	1.2	1.7	1.1
	Population (Thousands)	11.2	9.8	9.4	12.3	16.6	8.1
	Schools	7	7	7			7
	Dwelling Units (Thousands)	6.5	6.0	5.1			4.6
East	Land Area (Thousand Acres)	0.5	0.3	0.5	0.4	0.5	0.4
	Population (Thousands)	3.2	1.1	3.3	2.2	2.9	2.2
	Schools	1	1	1			1
	Dwelling Units (Thousands)	0.9	0.3	1.0			0.6

TABLE XI (cont.)

SECTOR*	ITEM	CONDITION: NEF 30 1	2	3	4	5	6
All Sectors	Land Area (Thousand Acres)	12.1	14.7	13.2	8.3	10.4	8.8
	Population (Thousands)	121.4	139.9	127.3	71.6	92.7	72.8
	Schools	70	78	74			46
	Dwelling Units (Thousands)	41.5	47.6	42.3			25.8

*See Figure 8 for a description of sector designations.

TABLE XI (cont.)

SECTOR*	ITEM	NEF 40 CONDITION 1	2	3	4	5	6
Southwest	Land Area (Thousand Acres)	0.4	0.6	0.4	0.3	0.4	0.3
	Population (Thousands)	1.1	4.3	1.0	0.1	0.1	0.1
	Schools	0	2	0			0
	Dwelling Units (Thousands)	0.3	1.2	0.3			0
Northeast	Land Area (Thousand Acres)	0.8	1.3	1.0	0.9	1.0	0.7
	Population (Thousands)	4.4	9.3	6.2	5.7	5.9	3.7
	Schools	3	3	3			3
	Dwelling Units (Thousands)	1.9	4.1	2.4			1.5
Northwest	Land Area (Thousand Acres)	0.9	0.3	1.0	0.4	0.5	0.4
	Population (Thousands)	16.4	2.9	15.4	4.3	6.9	3.8
	Schools	3	0	3			0
	Dwelling Units (Thousands)	4.8	0.8	4.5			1.0

TABLE XI (cont.)

SECTOR*	ITEM	NEF 40 CONDITION 1	2	3	4	5	6
Southeast	Land Area (Thousand Acres)	0.4	0.2	0.2	0.3	0.3	0.3
	Population (Thousands)	0.4	0.0	0.0	0.2	0.2	0.2
	Schools	0	0	0			0
	Dwelling Units (Thousands)	0.1	0.0	0.0			0.0
West	Land Area (Thousand Acres)	0.2	0.2	0.3	0.2	0.3	0.2
	Population (Thousands)	0.0	0.0	0.0	0.0	0.0	0.0
	Schools	0	0	0			0
	Dwelling Units (Thousands)	0.0	0.0	0.0			0.0
East	Land Area (Thousand Acres)	0.4	0.2	0.3	0.3	0.3	0.3
	Population (Thousands)	2.1	0.6	1.1	1.1	1.1	1.1
	Schools	0	0	0			0
	Dwelling Units (Thousands)	0.6	0.2	0.3			0.3

TABLE XI (cont.)

SECTOR*	ITEM	NEF 40 CONDITION 1	2	3	4	5	6
All Sectors	Land Area (Thousand Acres)	3.1	2.8	3.1	2.5	2.7	2.1
	Population (Thousands)	24.4	17.0	23.8	11.4	14.2	8.9
	Schools	6	5	6			3
	Dwelling Units (Thousands)	7.7	6.2	7.5			2.9

* See Figure 8 for a description of sector designations.

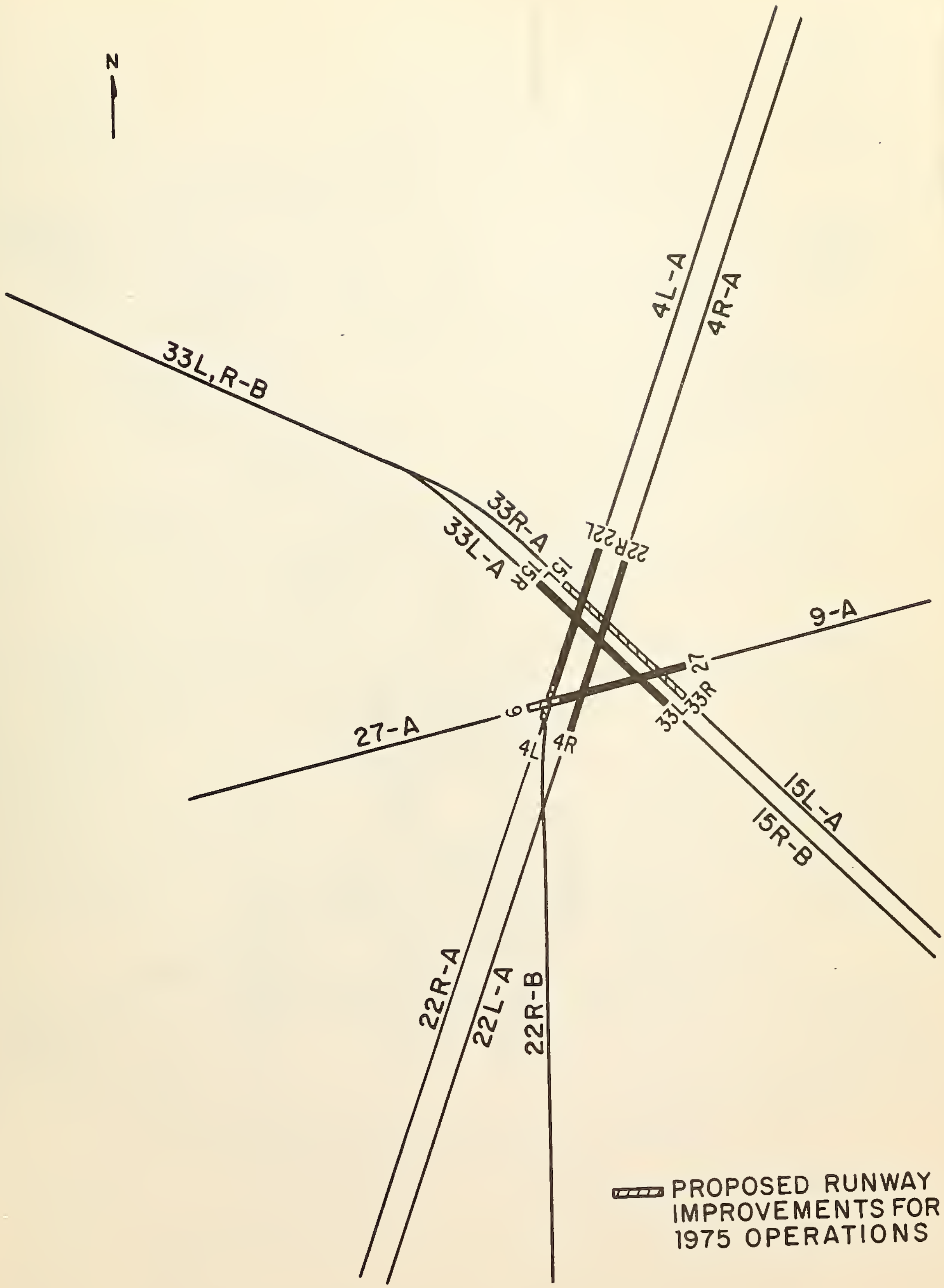


FIG. 1 MAJOR FLIGHT PATHS FOR BOSTON — LOGAN INTERNATIONAL AIRPORT

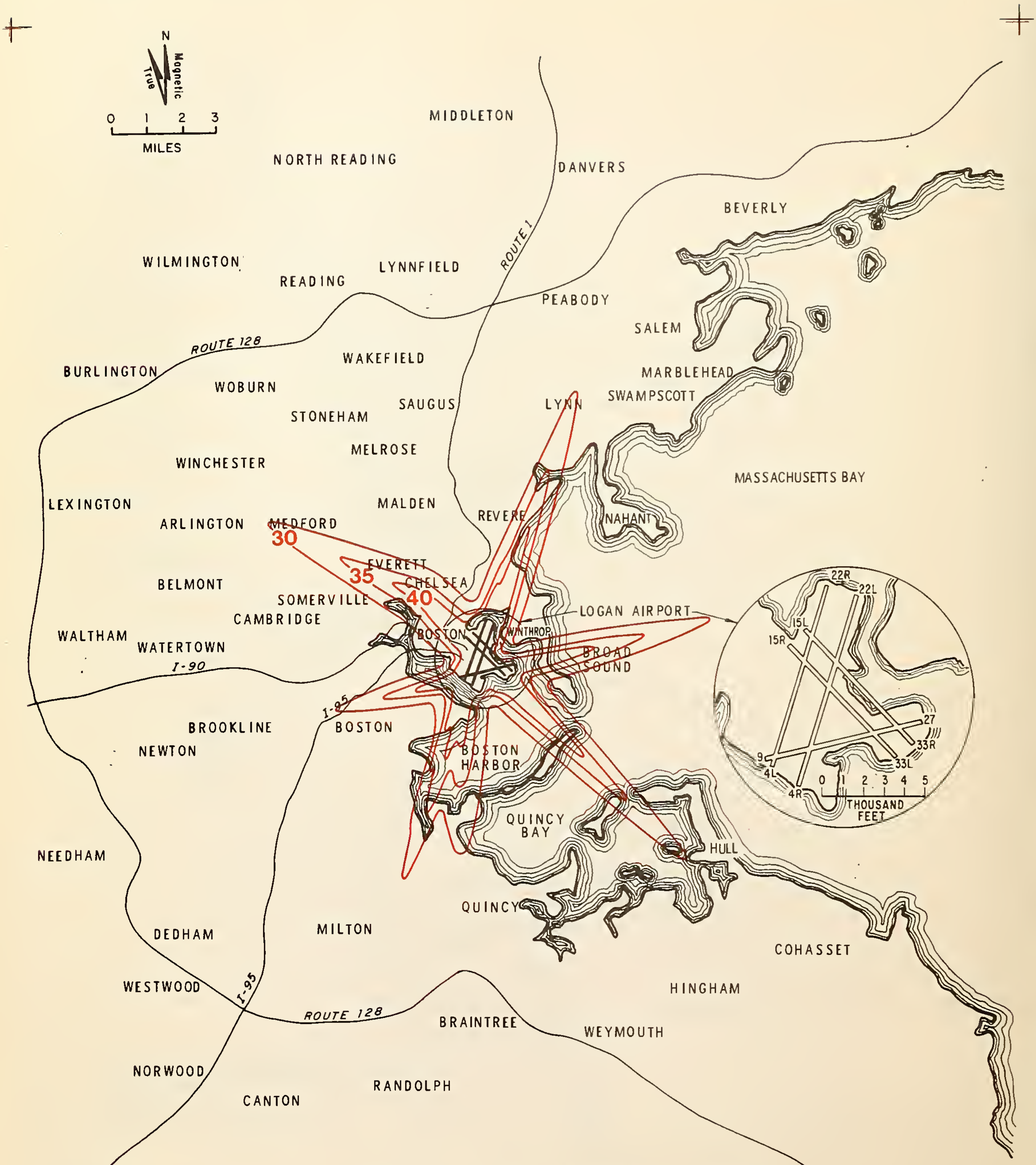


FIG. 2 NOISE EXPOSURE FORECAST CONTOURS
BOSTON – LOGAN INTERNATIONAL AIRPORT
1970

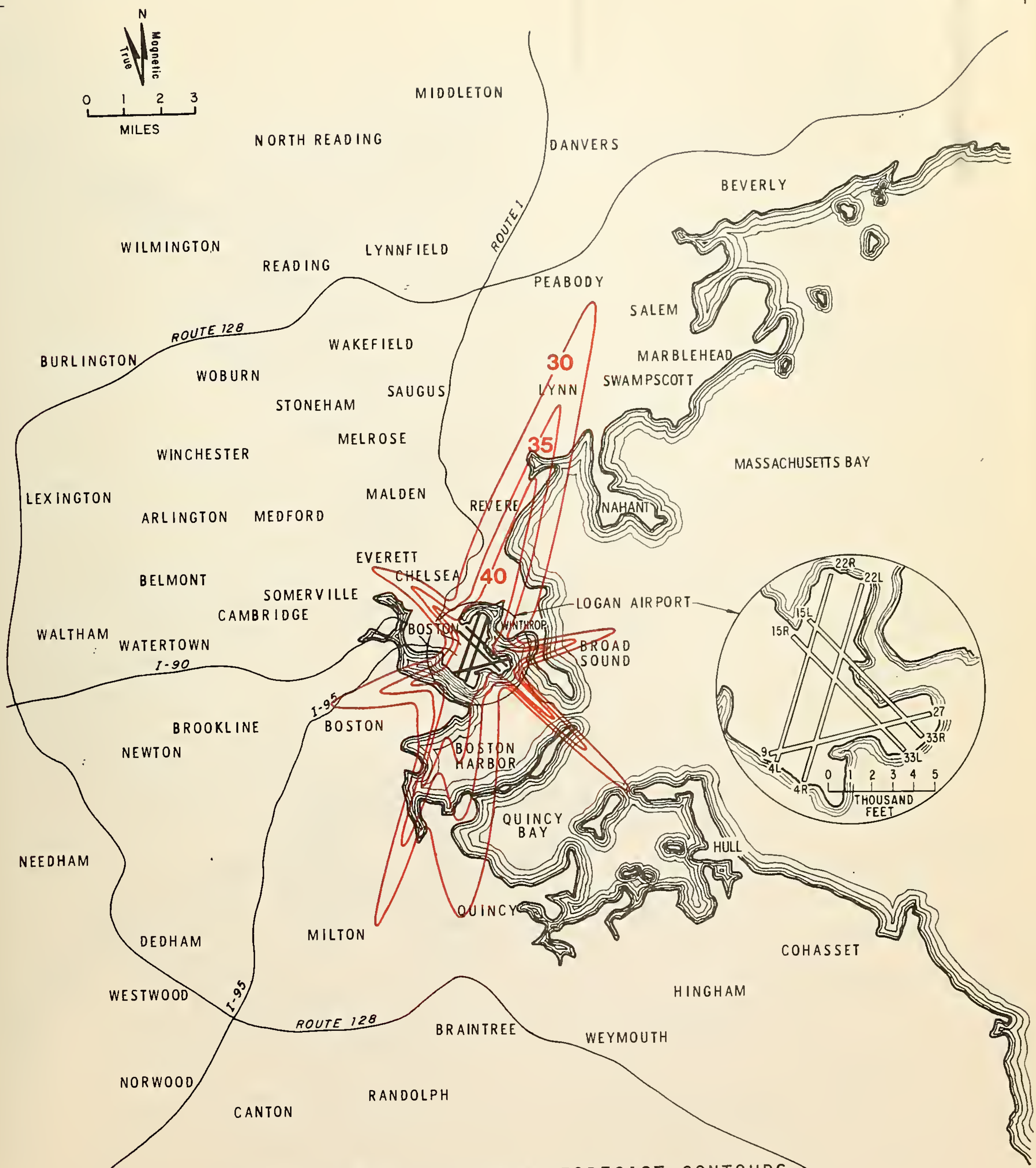


FIG. 3 NOISE EXPOSURE FORECAST CONTOURS
BOSTON – LOGAN INTERNATIONAL AIRPORT
1975-MAXIMUM CAPACITY

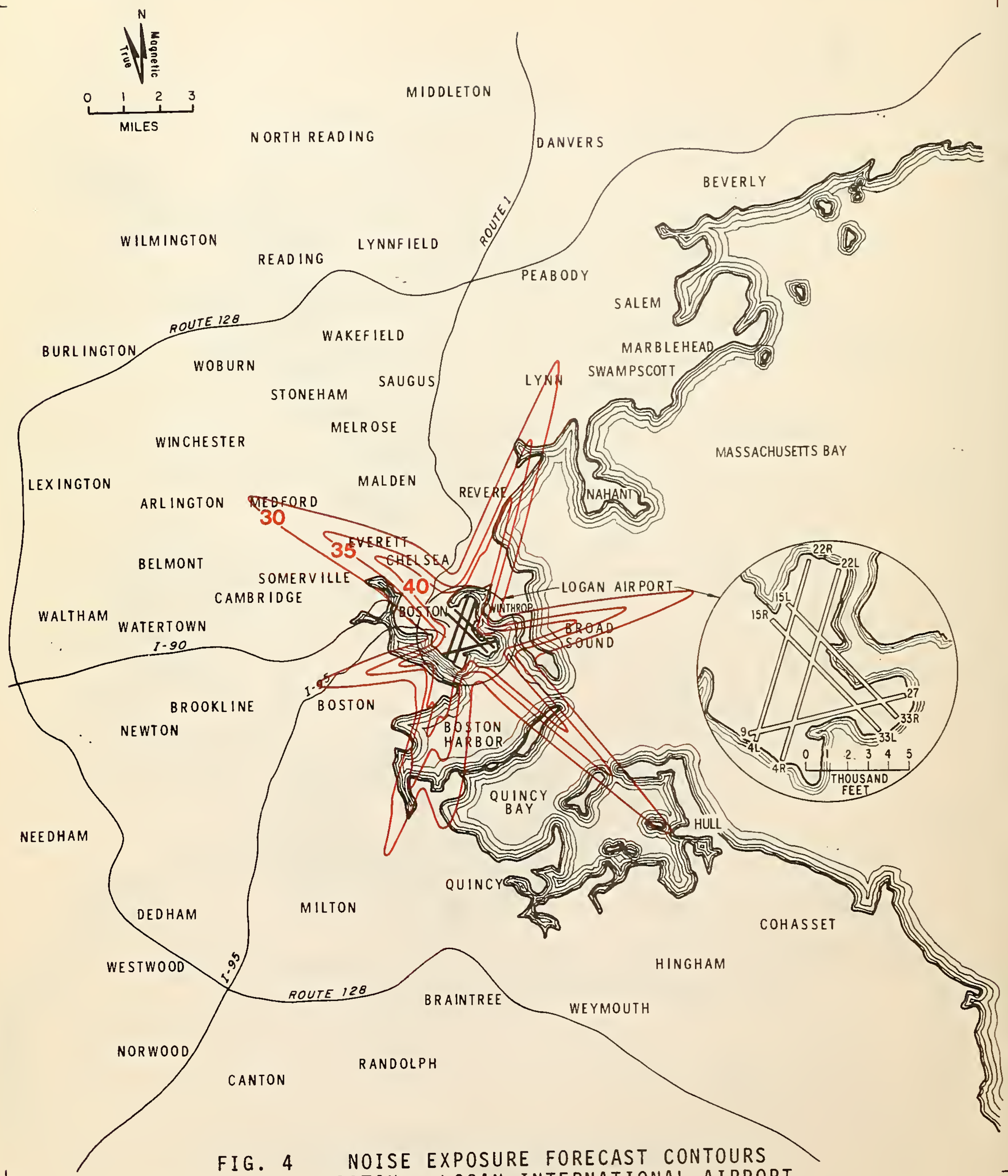


FIG. 4 NOISE EXPOSURE FORECAST CONTOURS
BOSTON — LOGAN INTERNATIONAL AIRPORT
1975-HISTORIC

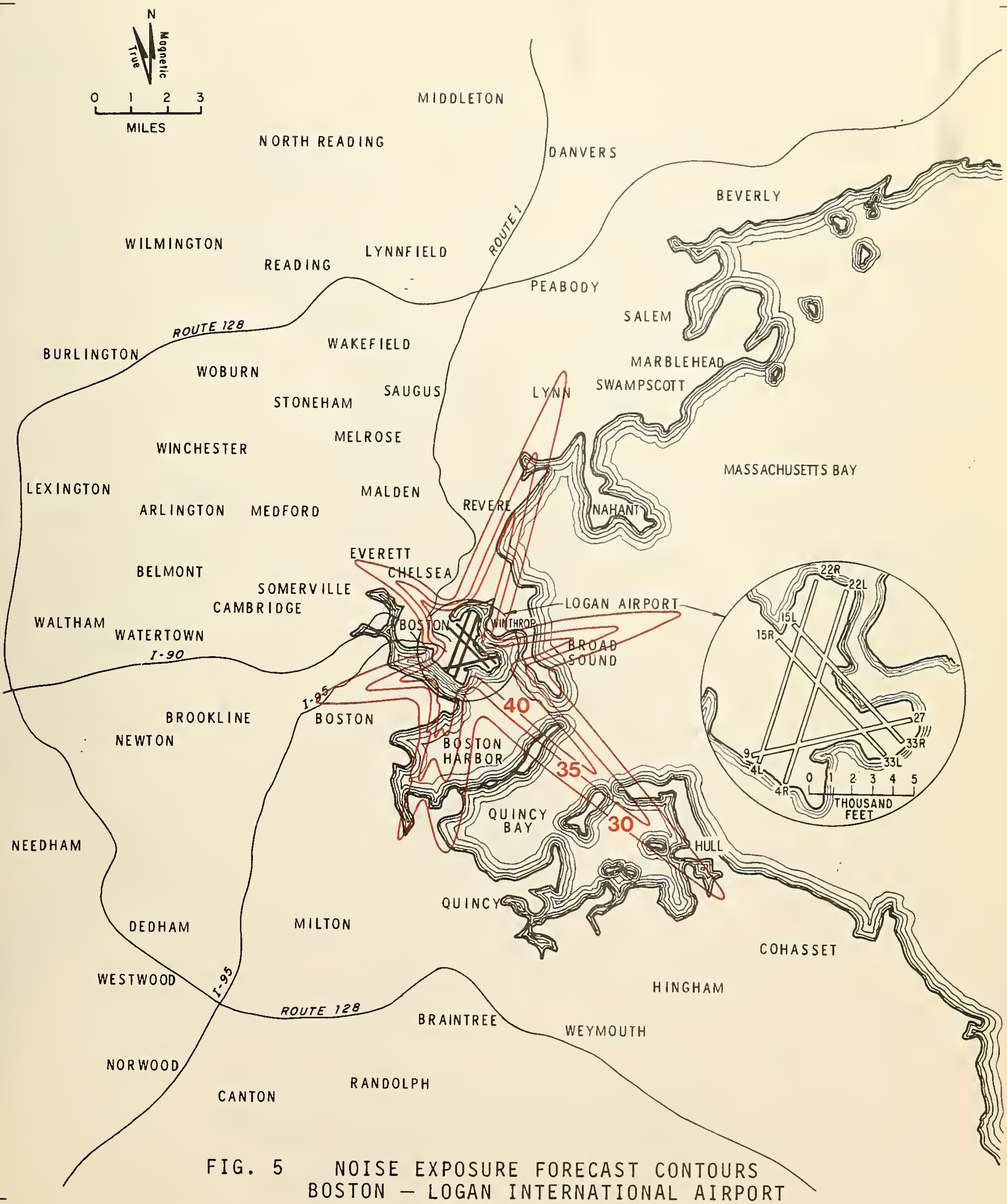


FIG. 5 NOISE EXPOSURE FORECAST CONTOURS
BOSTON — LOGAN INTERNATIONAL AIRPORT
1975-MAXIMUM NOISE ABATEMENT AND
EXISTING AIRPORT-ALTERNATE 1

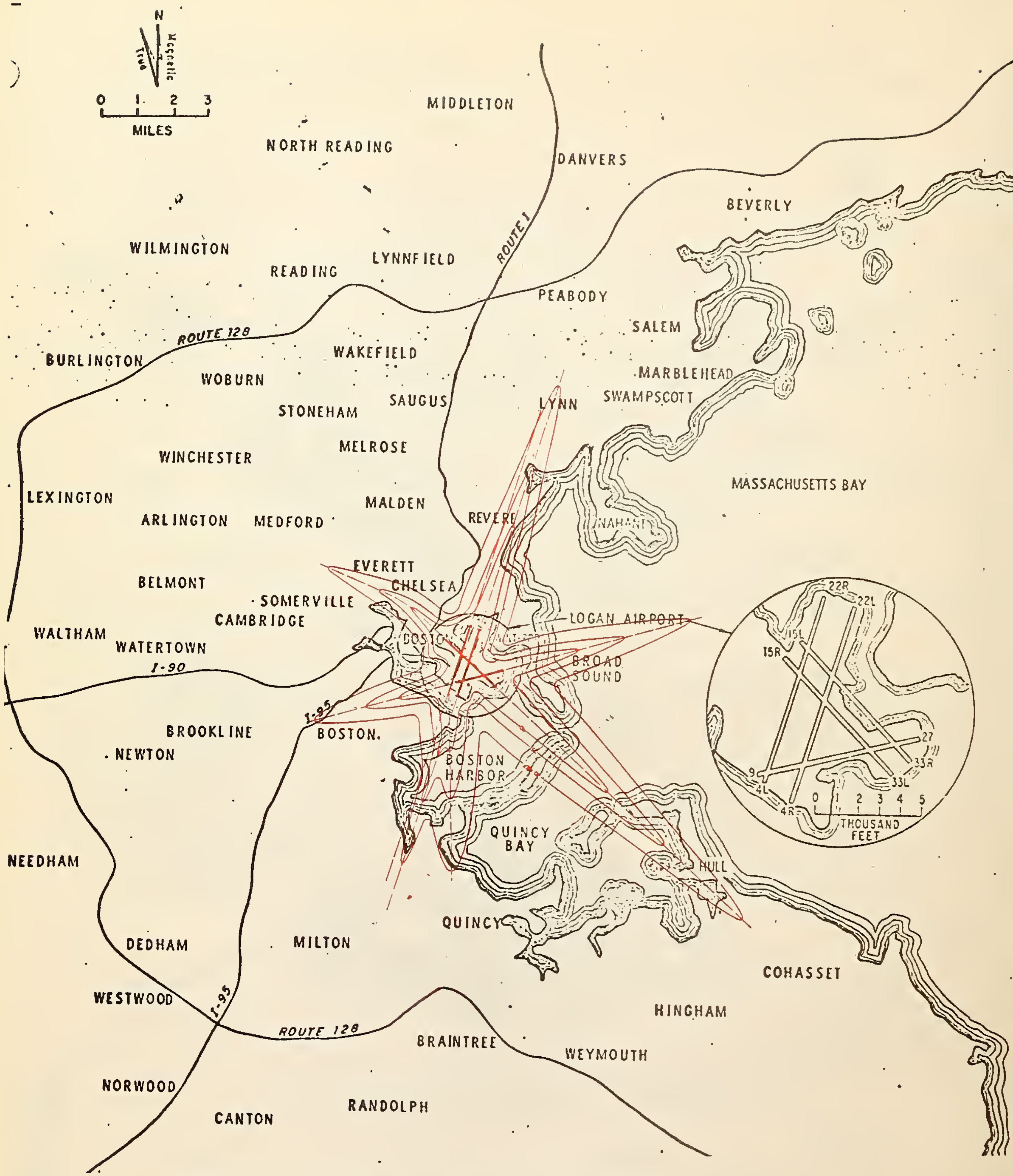


FIG. 6 MAXIMUM NOISE ABATEMENT, EXISTING AIRPORT CONFIGURATION 1975 OPERATIONS - ALTERNATE #2

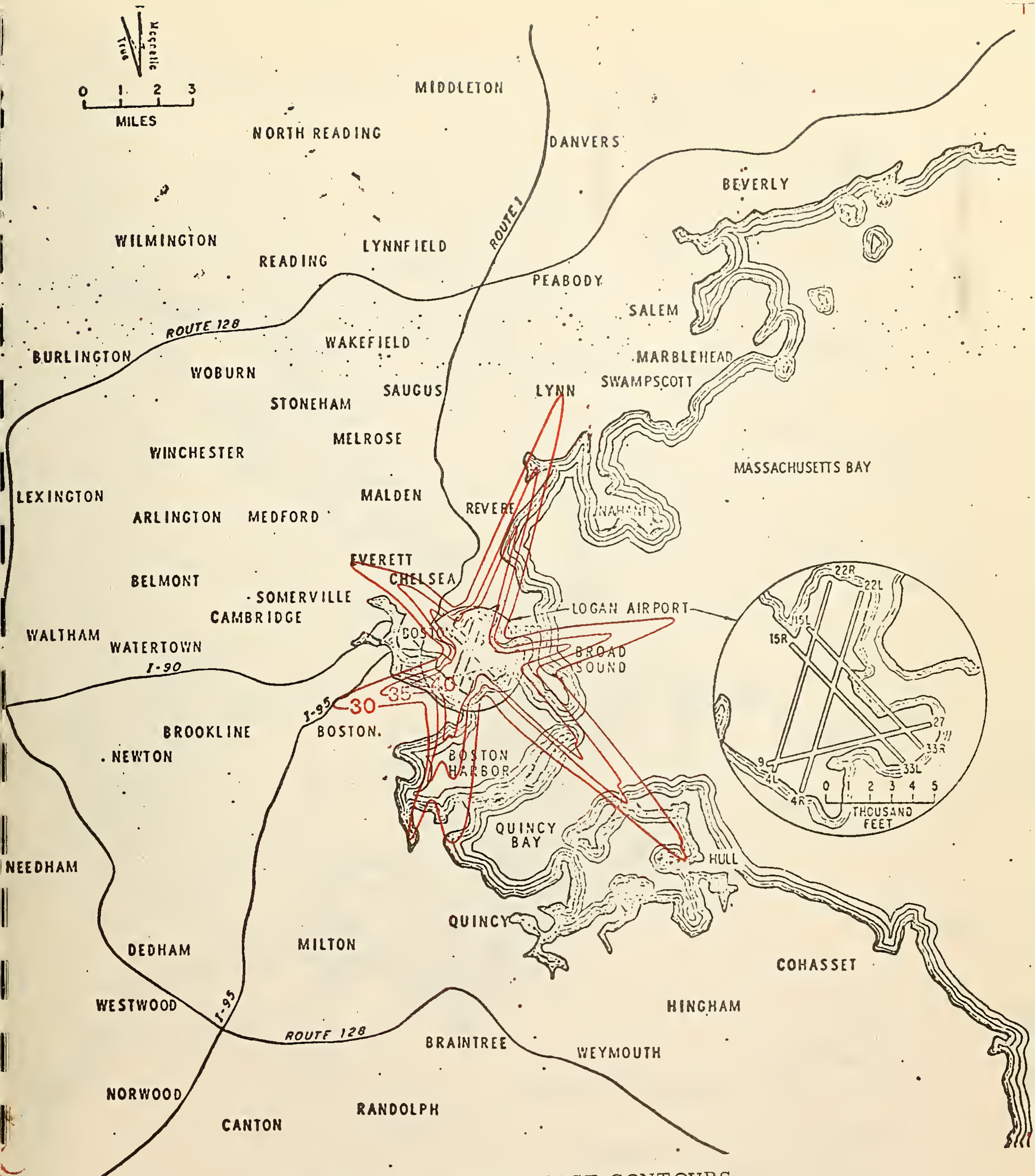


FIG. 7 NOISE EXPOSURE FORECAST CONTOURS
BOSTON - LOGAN INTERNATIONAL AIRPORT
1975-MAXIMUM NOISE ABATEMENT AND IMPROVED AIRPORT

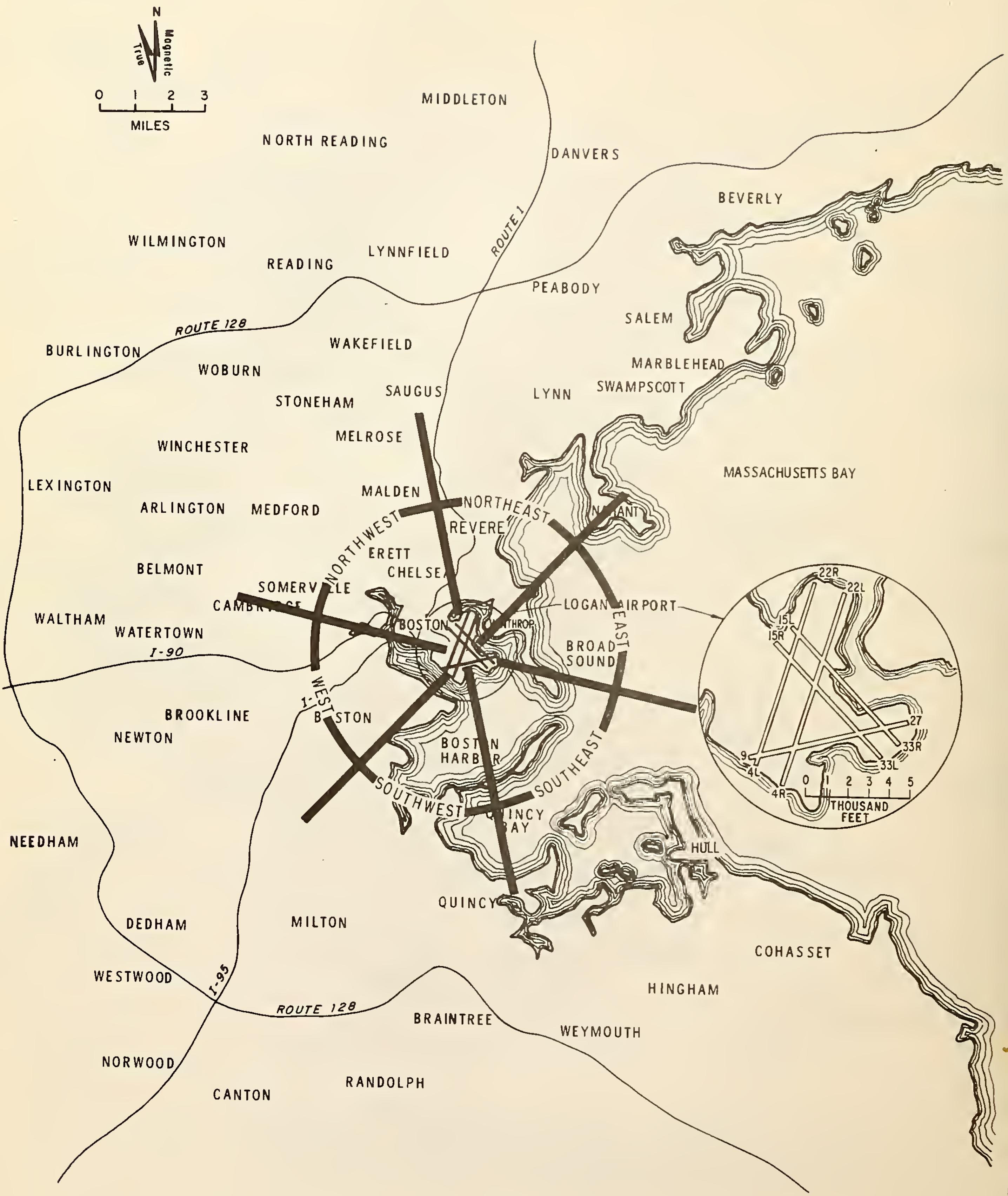


FIG. 8 BOSTON — LOGAN INTERNATIONAL AIRPORT AND VICINITY SECTORS

REPORT OF OCEANOGRAPHIC INVESTIGATION OF THE WATERS ADJACENT TO THE NORTHWEST RUNWAY AREA OF LOGAN INTERNATIONAL AIRPORT

Prepared for:

Booz-Allen Hamilton, Inc.
Environmental Resources Group

By:

EG&G, Inc.
Environmental Equipment Division
151 Bear Hill Road
Waltham, Massachusetts 02154

TABLE OF CONTENTS

SECTION 1.0 SUMMARY

The following report describes an investigation relating to the effects of the proposed land fill in the area northwest of Logan International Airport on the flushing characteristics of the body of water adjacent to the northwest runway and described in Figure 1.

Primarily, the purpose of the investigation has been to gather oceanographic, hydrographic and meteorological baseline data and apply predictive modeling techniques to forecast the probable effects of land fill on the dispersion and mixing patterns of the adjacent waters.

During the period April 9, 1971, through April 15, 1971, an intensive study of the area was undertaken, utilizing modern oceanographic techniques to maximize the value of the data. Measurements of currents, tide, wind and bathymetry were made, and predictive computer models were employed to provide the basis for the recommendations and conclusions herein.

The body of water studied has all of the characteristics of a tidal embayment with relatively high velocities at the entrance and weak and variable speeds within the embayment.

The source of water for flushing is the tides of Boston Harbor, entering and exiting through the channel at Mooring B. This embayment is utilized as a sink for the overflow sewer at the foot of Moore Street and provides an area for recreational activity, chiefly during the summer months. Of particular interest is the Orient Heights Beach area and the three yacht clubs in the area.

The baseline study indicates that the present scheme for dispersing the effluent of the sewer at the foot of Moore Street is inadequate and that, under

some conditions of tides and winds, the effluent from the sewer will flow towards the Orient Heights Beach.

The proposed fill area will reduce the volume of water available for dispersing the effluent from the sewer by 37% and, based on the predictive model plots, will tend to further reduce the dispersion in the vicinity of the Orient Heights Beach.

A detailed description of the investigation and its conclusions is contained herein.

SECTION 2.0

2.1 GENERAL

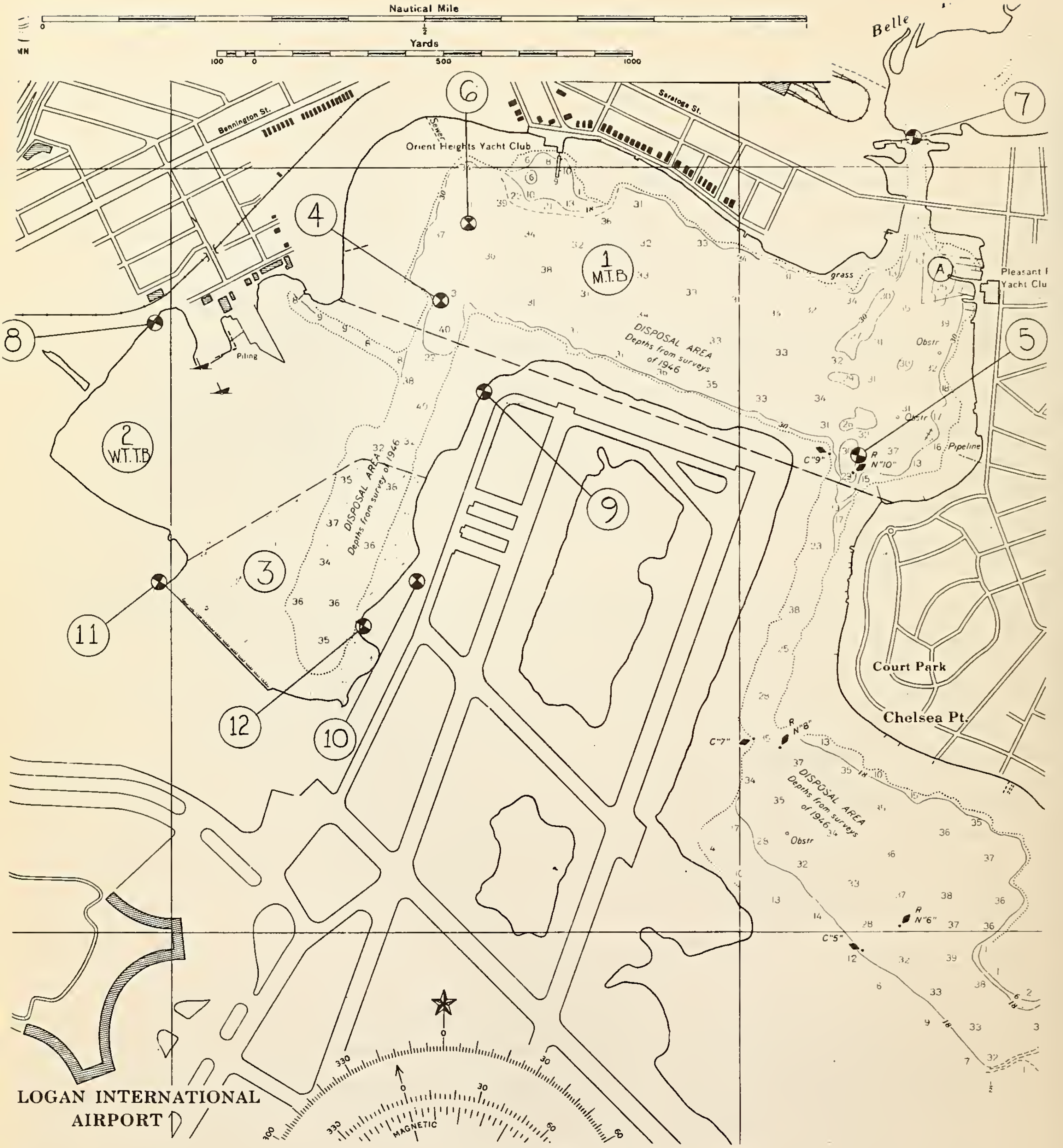
This report contains data, procedures and equipment used to investigate the waters depicted in Figure 1. The recommendations and conclusions are based on the above data and the analysis thereof by EG&G, Inc., with the assistance of Mr. Dean Bumpus, Senior Scientist at Woods Hole Oceanographic Institution, and Mr. Merv Palmer, Environmental Engineer at the Ontario Water Resources Board, acting as consultants to EG&G.

2.2 PURPOSE

The proposed runway, 15L-33R, will require filling an area of approximately 77,000 yards which is now flushed by tidal waters. The effects of this proposed land fill can be assessed and evaluated by initially establishing the baseline conditions prior to the land fill, applying predictive computer modeling techniques to the baseline data, analyzing the predictive data and providing the results on which sound engineering judgments can be made. Lastly, of course, is the requirement to compare the baseline data, predicted effects and the engineering judgments with the actual resulting conditions, should the land fill take place.

2.3 SCOPE

In order to provide the baseline data, EG&G conducted an oceanographic survey in the area depicted in Figure 1 - Legend 1 and described as the Main Tidal Basin, which is that body of water north of a line drawn from the East Boston Yacht Club, easterly through C "9" and N "10" on U.S. Coast and Geodetic Survey Chart No. SC248. Concurrently, data was taken in that area depicted in Figure 1 - Legend 2 and described as the Western Tributary Tidal



NOTE:

1. PLACE DROGUE TRACKS PLOT (FIG. 10) OVER FIGURE 1 ALIGNING ITEMS 9, 10 & 11, TRIANGULATION STATIONS 1, 2 & 3.

LEGEND

ITEM NO.	DESCRIPTION
1	MAIN TIDAL BASIN
2	WESTERN TRIBUTARY TIDAL BASIN
3	PROPOSED LANO FILL
4	MOORING "A"
5	MOORING "B"
6	MOORING "E"
7	BRIDGE - BELLE ISLE INLET
8	SEWER OUTFALL FOOT OF MOORE ST.
9	TRIANGULATION STATION 1
10	TRIANGULATION STATION 2
11	TRIANGULATION STATION 3
12	TIOE STATION

FIGURE 1

Basin, which is that body of water south of a line drawn from the East Boston Yacht Club easterly to the intersection of high ground at the airport property.

The data gathered in these two areas during the period of April 9, 1971, through April 15, 1971, was analyzed and applied to the predictive models developed by Mr. M. Palmer of the Ontario Water Resources Board.

NOTE - Figure 1 has been attached to this report as a pullout drawing. It is the basic geographical reference for this report and provides the reader with the necessary orientation to comprehend this report.

SECTION 3.0

3.1 FIELD PROGRAM

A comprehensive field program of data acquisition, under the direction of Mr. Robert Henderson, Project Engineer, and Mr. Paul Ferris Smith, Staff Oceanographer, of EG&G, Inc., commenced on April 9, 1971, and concluded on April 15, 1971. The data acquisition phase consisted of the measurement of currents, tides, wind, and bathymetry.

3.1.1 Currents

Two methods were utilized to determine the prevailing currents in the area investigated:

1. Four Model 102 self-contained digital recording current meters were installed on April 9, 1971, at the following locations:

Mooring A	Figure 1	Legend 4
Mooring B	Figure 1	Legend 5
Mooring E	Figure 1	Legend 6
Bridge	Figure 1	Legend 7

These locations were chosen to monitor the current patterns at key points in both areas, the Main Tidal Basin and the Western Tributary Tidal Basin.

Mooring A was located to adequately describe the flushing in and out of the Western Tributary Tidal Basin (Figure 1 - Legend 4). Mooring B was located to describe the flow in and out of the Main Tidal Basin (Figure 1 - Legend 5). Mooring E was located to increase the validity of predictive modeling techniques with respect to potential pollution effects on Orient Heights Beach (Figure 1 - Legend 6). The bridge (Figure 1 - Legend 7) installation at Belle Isle Inlet provided data to calculate the mass balance in the Main Tidal Basin and the Western Tributary Tidal Basin.

These instruments recorded current speed and direction continuously, sampling every five seconds, from April 9, 1971, to April 15, 1971. (Each instrument with the exception of the bridge installation was located 7 feet below the surface of the water on a slack mooring which allowed it to remain 7 feet below the surface throughout the survey. The bridge installation was set with the sensors at a fixed depth of 3 feet below mean low water.) Pertinent instrument identification data is tabulated on Figure 2. Each instrument performed reliably, and 100% data acquisition was achieved. Descriptive data and specifications on the Model 102 is contained in Appendix II. Data results are discussed in Section 3.2.1.

2. Parachute drogues (Figure 3) were utilized on April 14, 1971, and April 15, 1971, to describe surface current conditions throughout the tidal cycles in and around the area described as the Western Tributary Tidal Basin. Of particular interest were the surface currents in the vicinity of the sewer outfall at the foot of Moore Street (Figure 1 - Legend 8). The fresher sewer water will tend to remain close to the surface until thoroughly mixed, and near-surface measurements are, therefore, required. The drogues were set with a scope to minimize the effect of the marsh grass as the tide receded. The drogues were tracked by theodolite from three stations (Figure 1 - Legend 9) on shore. Using a small boat for positive siting and identification, the position of each drogue was triangulated with respect to time and plotted geographically. In addition, the drogue data was entered into a computer and velocity and direction completed. The results of the data are presented in Section 3.2.2.

3.1.2 Tides

Tides were measured during the period April 9, 1971, through April 15, 1971. A tide station was located on airport property (Figure 1 - Legend 10) in order to monitor heights and ranges of the tides throughout the period of the survey. Knowledge of the tidal prism is required for mass balance calculations.

The tide gage, as described in Appendix II, recorded reliably, and the data results are presented in Section 3.2.3.

CURRENT METER STATION DATA

DESCRIPTION	Mooring "A"
LOCATION	42° 22' 45" 71° 00' 30" depth 7'
SERIAL NUMBER	394
FILM NUMBER	401404
TIME START	11:39 - April 9, 1971
TIME END	11:35 - April 15, 1971
Figure 1 Reference	Legend 4
DESCRIPTION	Mooring "B"
LOCATION	42° 22' 40" 70° 59' 48" depth 7'
SERIAL NUMBER	377
FILM NUMBER	401403
TIME START	11:00 - April 9, 1971
TIME END	10:55 - April 15, 1971
Figure 1 Reference	Legend 5
DESCRIPTION	Mooring "E"
LOCATION	42° 22' 55" 71° 00' 26" depth 7'
SERIAL NUMBER	399
FILM NUMBER	401405
TIME START	11:52 - April 9, 1971
TIME END	11:20 - April 15, 1971
Figure 1 Reference	Legend 6
DESCRIPTION	Bridge Installation
LOCATION	42° 23' 02" 70° 59' 40" depth fixed 10'
SERIAL NUMBER	398
FILM NUMBER	401402
TIME START	18:30 - April 9, 1971
TIME END	9:45 - April 15, 1971
Figure 1 Reference	Legend 7

Figure 2

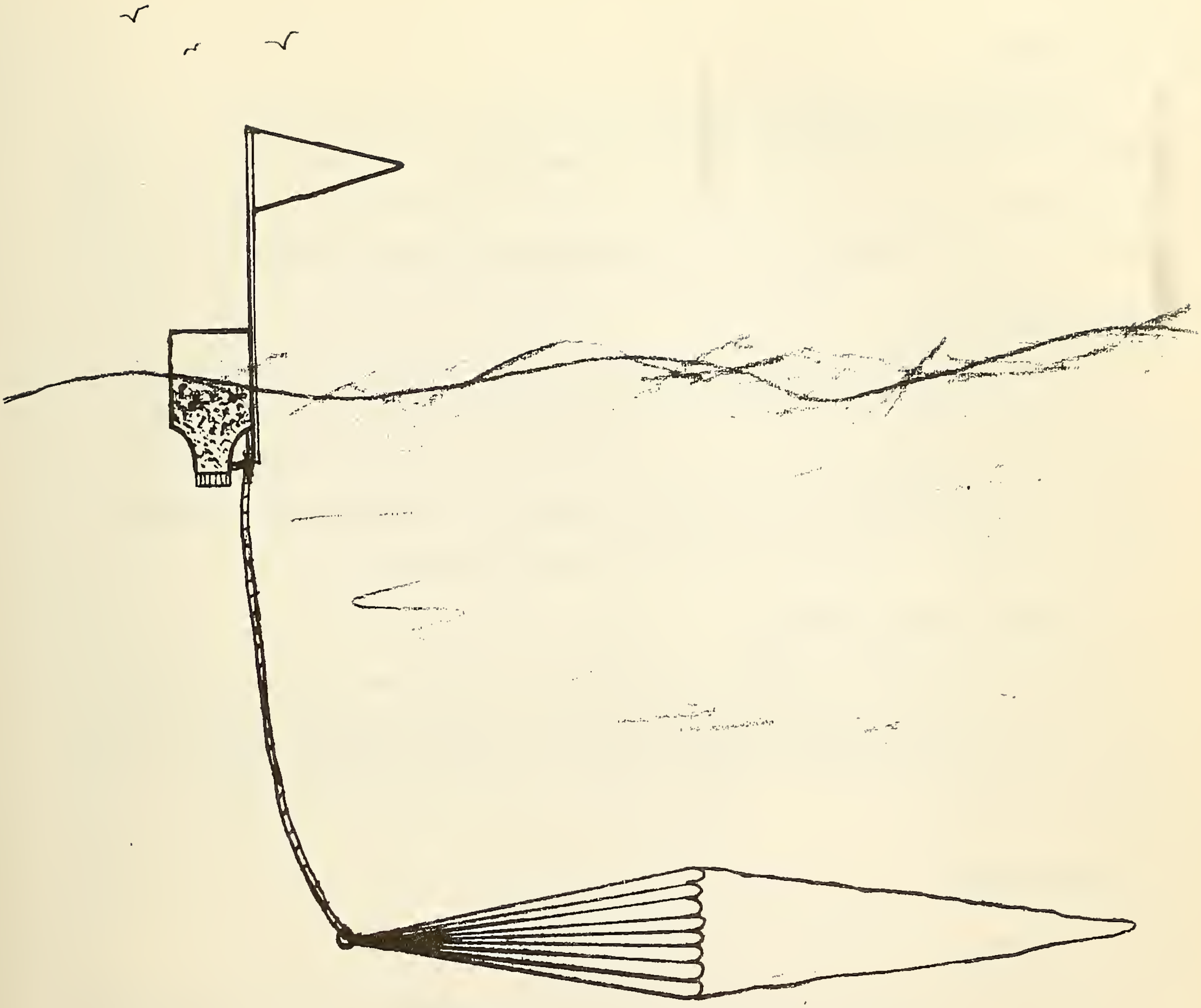


Figure 3 Current Drogue

3.1.3 Winds

Prevailing wind conditions during the period of the drogue survey, April 14, 1971, and April 15, 1971, were monitored at the Logan Airport Tower by the National Oceanographic and Atmospheric Agency National Weather Service and reported every 30 minutes. The wind data is presented in Section 3.2.4.

3.1.4 Bathymetry

Depth soundings were made at all locations pertinent to the survey area. All soundings, with the exception of the depth at the bridge installation, were made using a Bludworth depth recorder, which is accurate to ±.2% of water depth. Depth of the water at the bridge (Figure 1 - Legend 7) was determined with a lead line. Bathymetric data is discussed in Section 3.2.5.

3.1.5 Field Program Results

The data acquisition phase of the program was 100% successful. All instruments operated satisfactorily throughout the period April 9, 1971, through April 15, 1971, and provided the data base required to utilize computer predictive models.

3.2 DATA BASE

3.2.1 Currents

All four current meter records processed in accordance with the procedures described in Appendix I are presented here in a number of graphical forms, some of which are described in more detail in Section 4.0, Computer Predictive Modeling.

In each case, the digital film record from the current meter is transferred to IBM magnetic tape format on a specially designed computer reader (see Appendix I). The IBM tape is then decoded, making information available for graphical and numerical presentation. Several graphical representations are employed here.

Figures 4a, 5a, 6a, 7a	Direction Histograms in polar coordinates of each current station, indicating prevalent current directions and other influencing factors.
Figures 4b, 5b, 6b, 7b	Speed Histograms in rectangular coordinates for each station.
Figures 4c, 5c, 6c, 7c	Scatterplot of Speed Versus Direction, which provide graphical representations of predominant current speed and direction for each station.
Figures 4d, 5d, 6d, 7d	Progressive Vector Plots depicting virtual particle displacement for each station.
Figure 8	Vector Average Plot
Figure 9	Composite Vector Average

The figures for each station are discussed in the following paragraphs.

FIGURE 4a

Bridge Installation, Reference Figure 1 - Legend 7

Direction Histogram in Polar Coordinates of the Current Flow at the Bridge Installation

As might be expected from examination of the bathymetry of the particular area, the current direction follows the configuration of the channel; that is to say, 30° and 210° magnetic. No anomalies are apparent, nor should they be expected in such a confined area.

Figure 4a

Direction Histogram
Bridge Installation

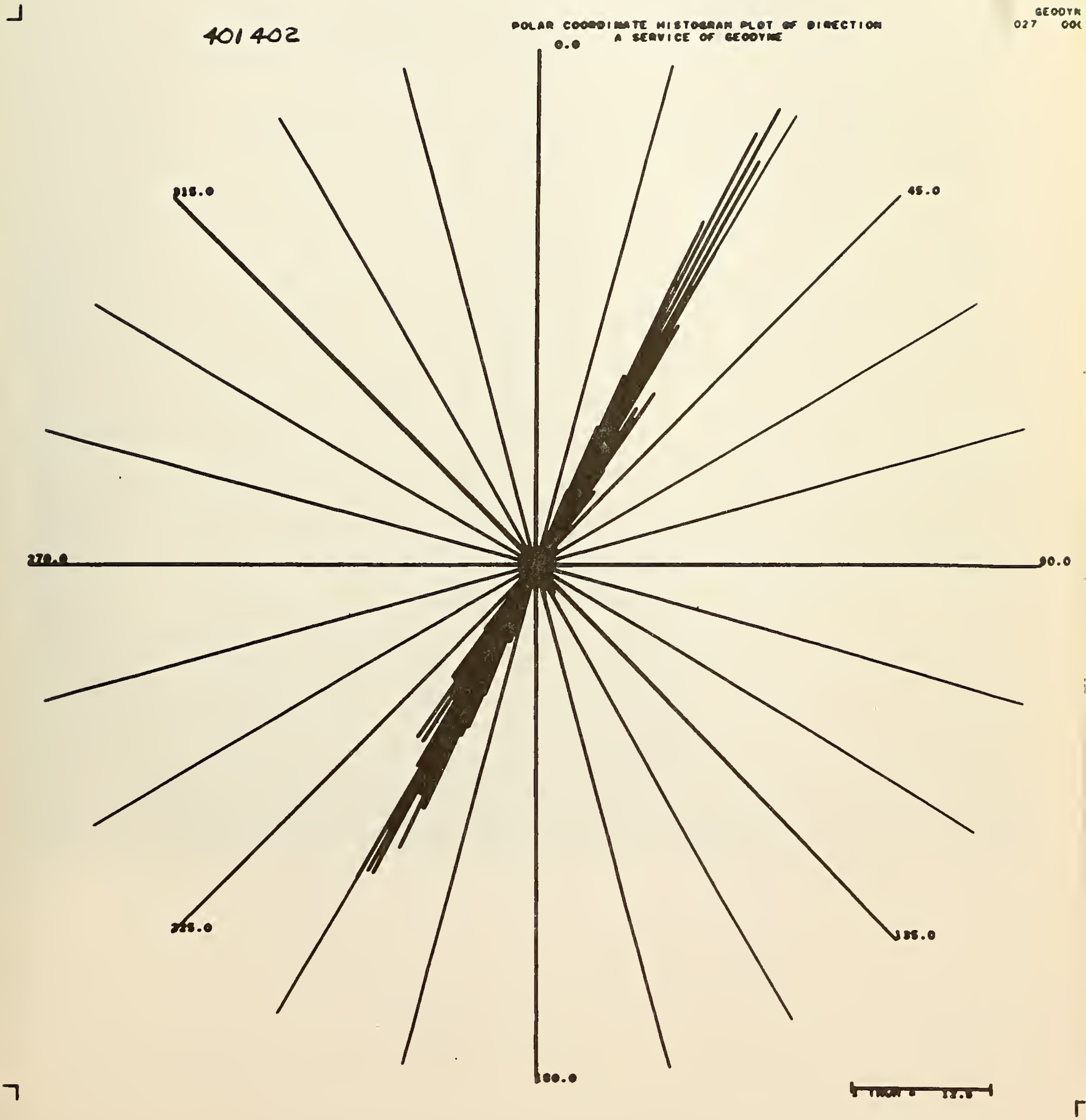


FIGURE 4b

Bridge Installation, Reference Figure 1 - Legend 7

Speed Histogram in Rectangular Coordinates of the Current Speed at the Bridge Installation

Maximum flows of 1.44 knots were detected at this location; however, speeds of .8 and 1.2 knots dominate the data.

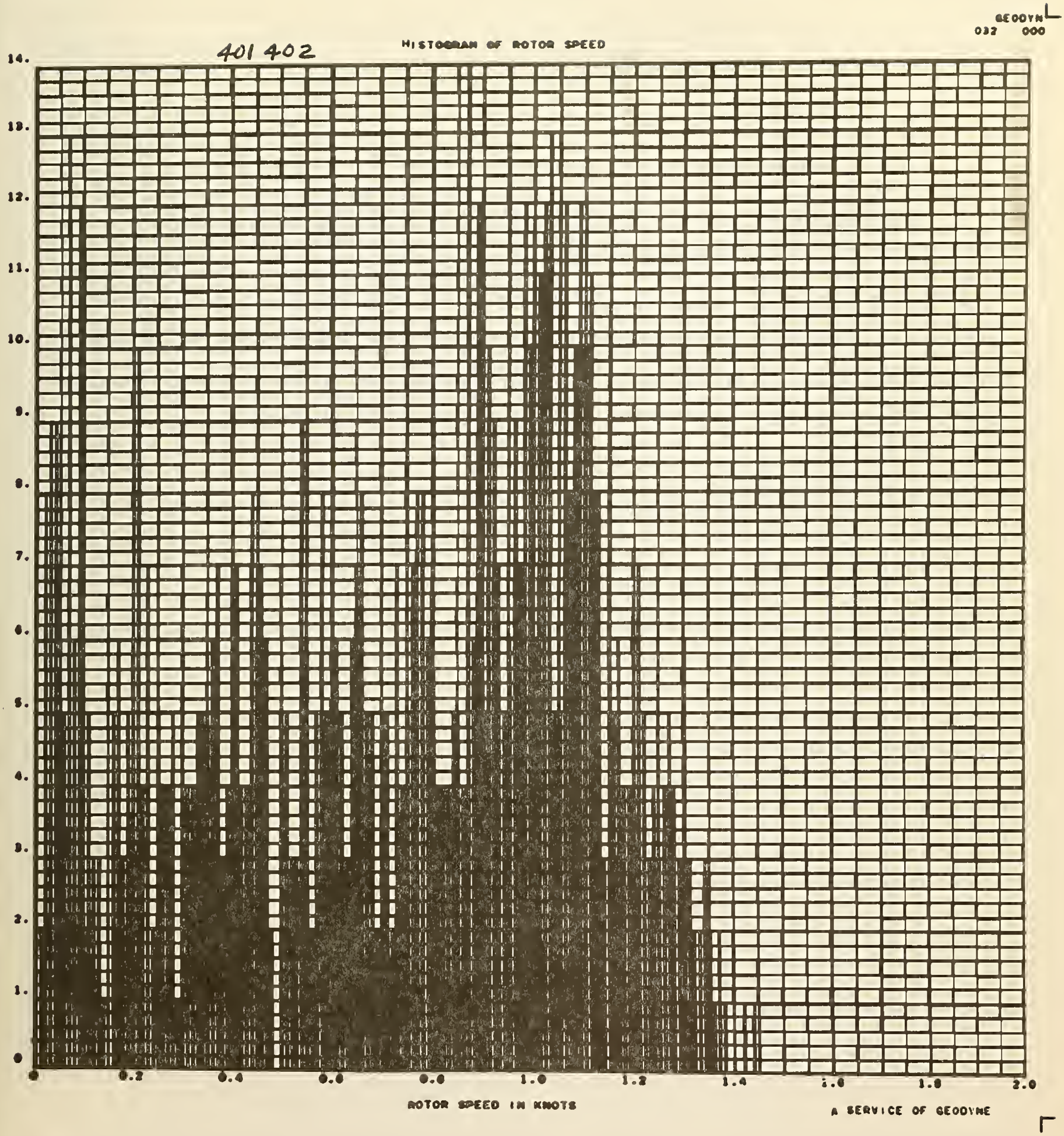


Figure 4b

Speed Histogram
Bridge Installation

FIGURE 4c

Bridge Installation, Reference Figure 1 - Legend 7

Scatterplot of Speed Versus Direction for the Bridge Installation

Here the dominant directions are 30° and 210°, corroborating the direction histogram. This data further shows that the speeds encountered on the incoming tide (30°) are about .2 knots less than those encountered on the outgoing tide (210°). This, of course, is due to the relative depths in the area.

Figure 4c

Scatterplot of Speed Versus Direction
Bridge Installation

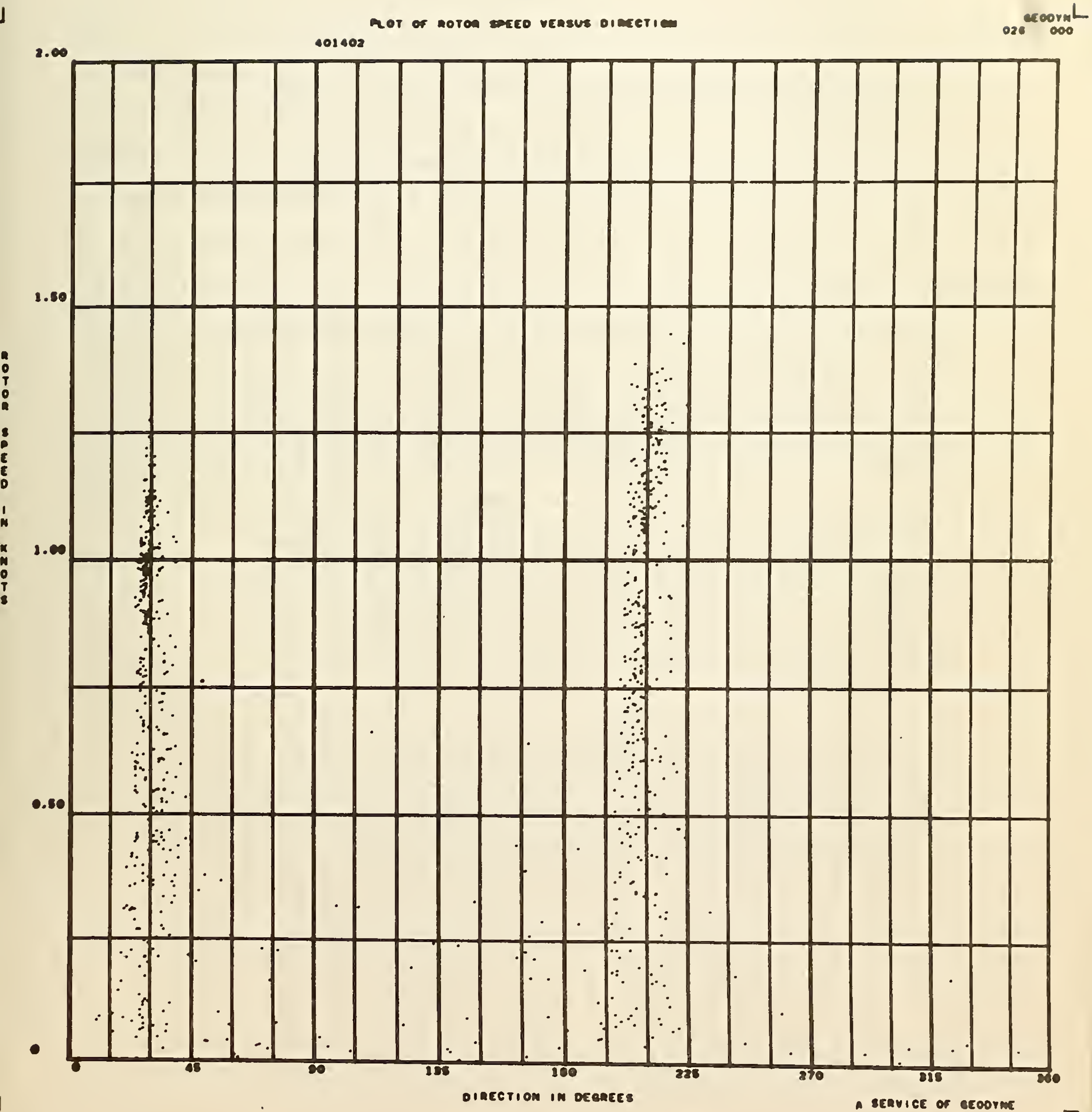


FIGURE 4d

Bridge - Belle Isle Inlet

Progressive Vector

Another particularly revealing and useful method of presenting the results of current meter time series recordings is the progressive vector diagram, sometimes known as the vector displacement diagram. In a Woods Hole Oceanographic Institution report, Reference No. 64-55, entitled "Processing Moored Current Meter Data," by Dr. Ferris Webster, he discusses the technique as follows:

> "Each point of the diagram is determined by multiplying the corresponding velocity by the time elapsed since the previous point and adding the resultant vector displacement to the sum of previous displacements. In this manner, a series of positions is obtained, which begins at point zero and has a resemblance to the path of a particle trajectory.
>
> It is tempting to think of the vector displacement diagram as a particle trajectory, but this can be misleading. Only in the special case where the field of motion is independent of position over the spatial scale of the vector diagram would the progressive vector diagram correspond to a true particle trajectory. Such a condition would seldom occur in a real situation.
>
> The vector displacement diagram is usually plotted with points spaced at uniform intervals of time. Each point can correspond to one current meter measurement, but this usually results in too many points. More commonly, one point on the diagram corresponds to the vector averaged velocity determined over many points."

Using the progressive vector program on the 10-minute averages, a plot tape is generated and a numerical summary produced for each of the current meter records. The plot tape is then plotted automatically by a Cal-Comp Plotter, and these plots are each presented here as Figures 4d, 5d, 6d, 7d. It should be noted that, in addition to the caution mentioned above in the excerpt from Dr. Webster's paper, in a tidal estuary the value of the computed net displacement given in the tabulation will depend upon the number of tidal cycles included in the record. Thus, these numbers should not be used for computation purposes. In the present case, since the total embayment is neither filling nor emptying, net displacement must be zero.

The graphical plots resulting from the progressive vector computations, however, are extremely informative especially insofar as they represent the flow patterns and the changes in these patterns resulting from such factors as strength of the wind.

Shown in Figure 4d, the progressive vector from Belle Isle Inlet, is the back-and-forth flooding and ebbing to be expected in the narrow inlet, with little variability throughout the record.

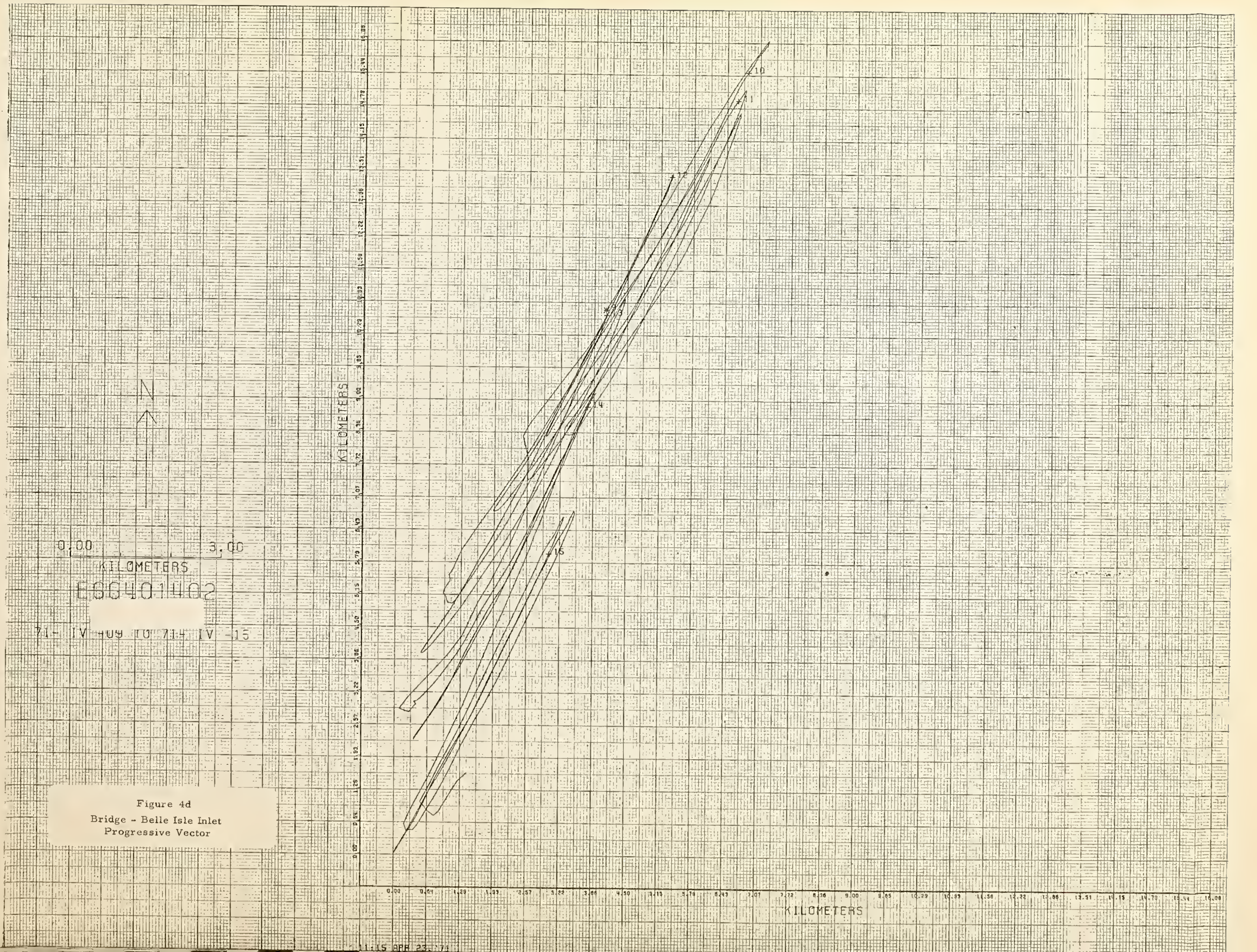


Figure 4d
Bridge - Belle Isle Inlet
Progressive Vector

FIGURE 5a

Mooring B, Reference Figure 1 - Legend 5

Direction Histogram in Polar Coordinates of the Current Flow at Mooring B, the Major Entrance and exit of the Main Tidal Basin Waters

The dominant directions of the current are obviously tidal induced, running in the direction of the channel; i. e., 40° and 220° magnetic. Some evidence of turning effects, causing an occurrence of easterly directions, is evident. This is due, most likely, to the bottom topography effect of the Winthrop shoreline during the ebb tides.

Figure 5a

Mooring B
Direction Histogram

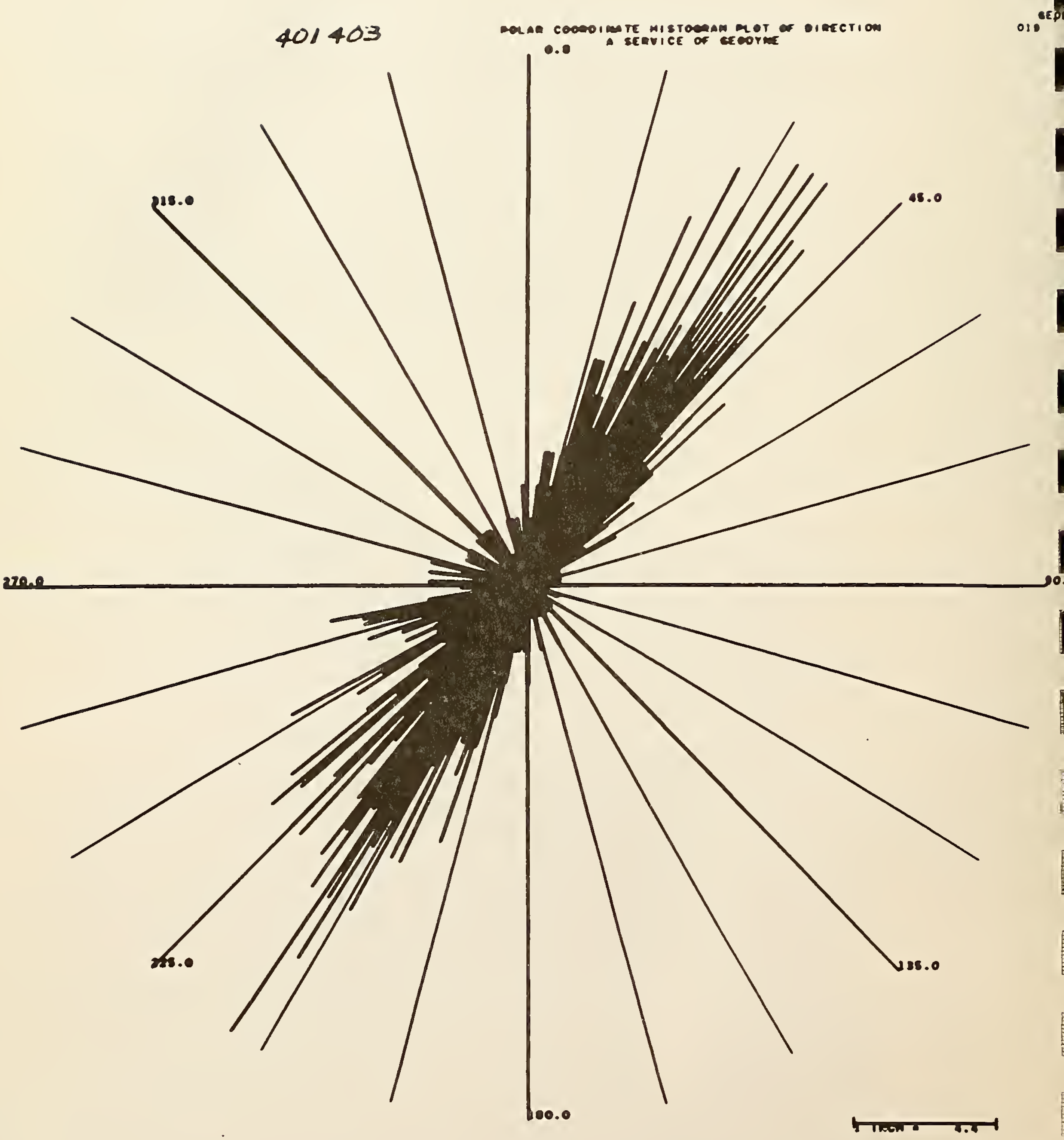


FIGURE 5b

Mooring B, Reference Figure 1 - Legend 5

Speed Histogram in Rectangular Coordinates of the Current Speed at the Entrance to the Main Tidal Basin

Maximum flows of .92 knots were detected; however, speeds of .3 to .7 knots dominate the data.

Figure 5b
Mooring B
Speed Histogram

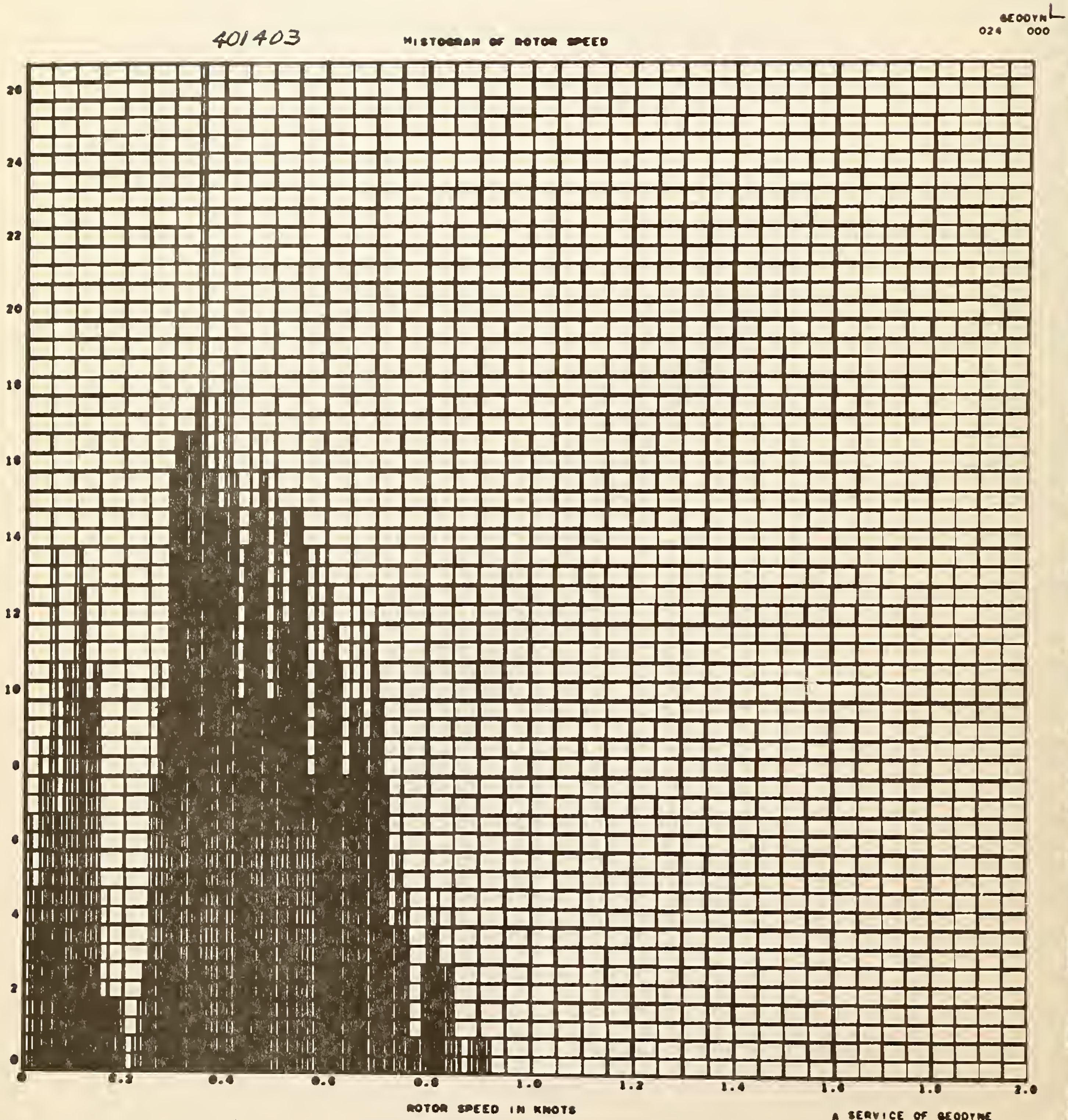


FIGURE 5c

Mooring B, Reference Figure 1 - Legend 5

Scatterplot of Speed Versus Direction for the Entrance to the Main Tidal Basin

The current tends to be extremely directional on the incoming tide (40°), reaching speeds as high as .92 knots. This is due to the water tending to be channeled on the incoming tides, whereas on the outgoing tide the speeds do not exceed .75 knots, and again the turning effect is evident in the occurrence of currents in the 270° direction.

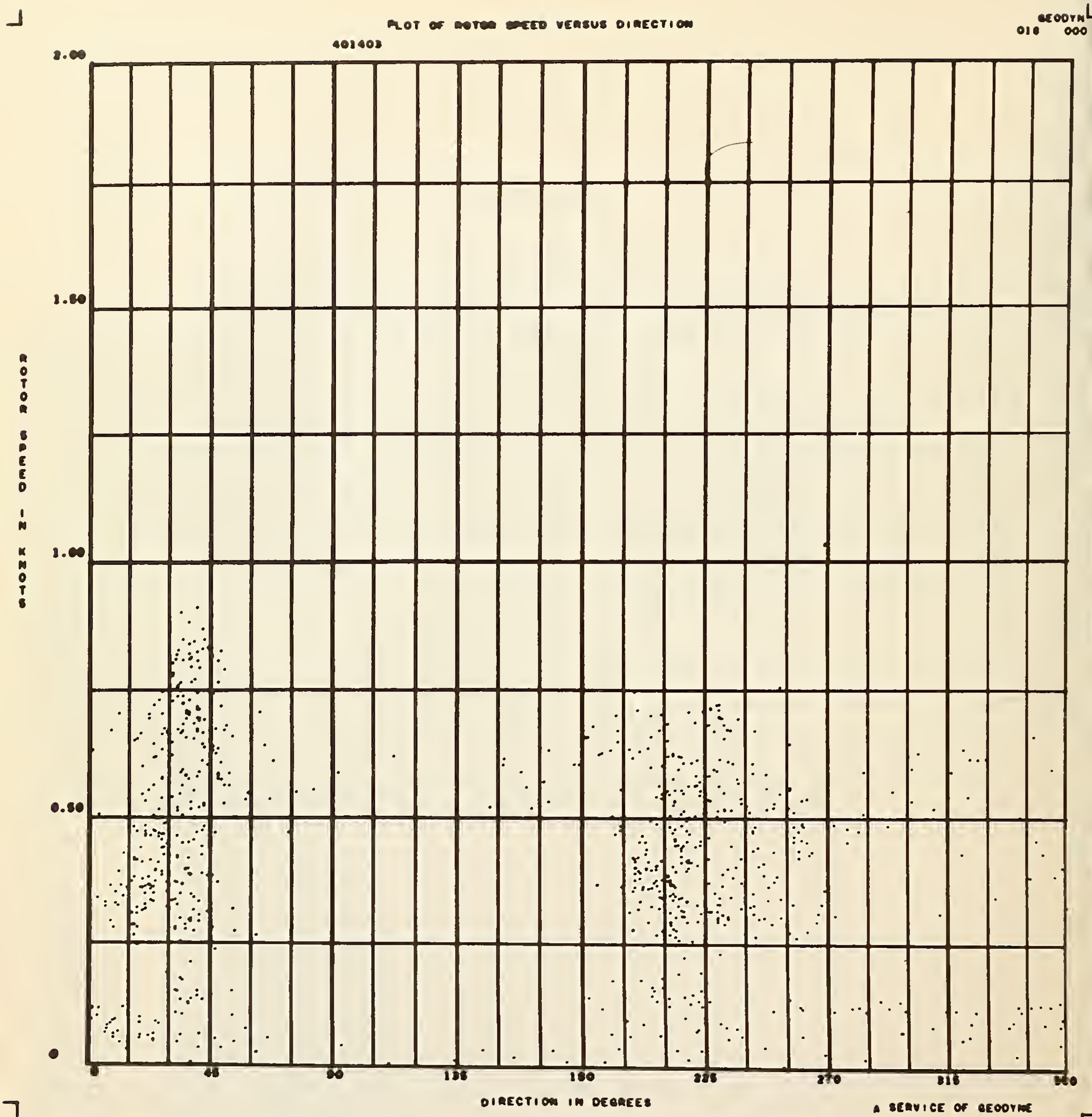


Figure 5c

Mooring B

Scatterplot of Speed Versus Direction

FIGURE 5d

Mooring B - Progressive Vector

The progressive vector for Mooring B, the main channel, shows a great deal of variability from day to day. During the period from April 13, 1971, through April 15, 1971, it seems reasonable to assume that the increased surface velocities are directly attributable to the strong winds which prevailed at this time.

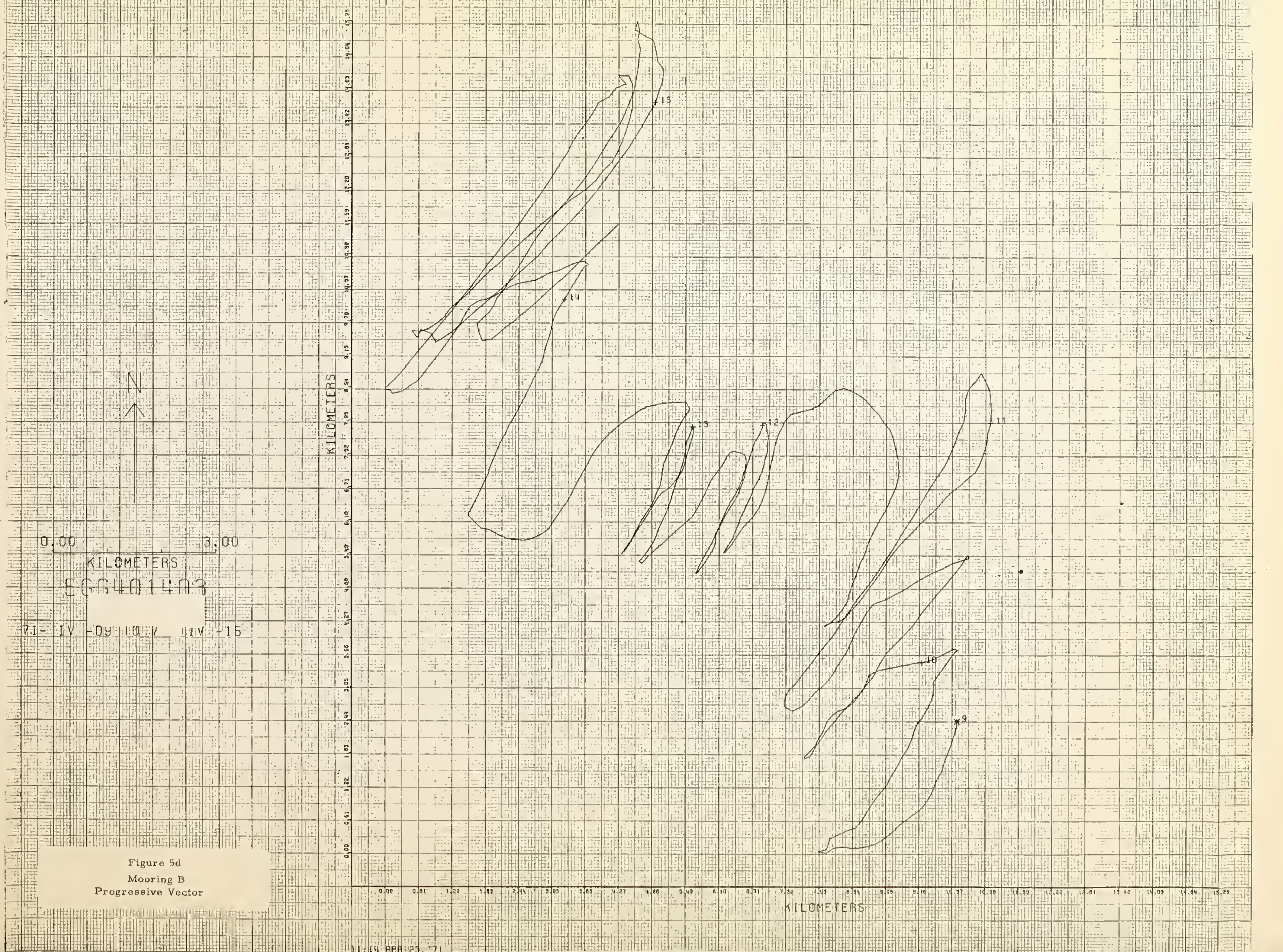


Figure 5d
Mooring B
Progressive Vector

FIGURE 6a

Mooring A, Reference Figure 1 - Legend 4

Direction Histogram in Polar Coordinates of the Current Flow at the Entrance to the Western Tributary Tidal Basin

The dominant directions of the current are obviously running in the direction of the channel (45° and 225° magnetic).

401 4C4

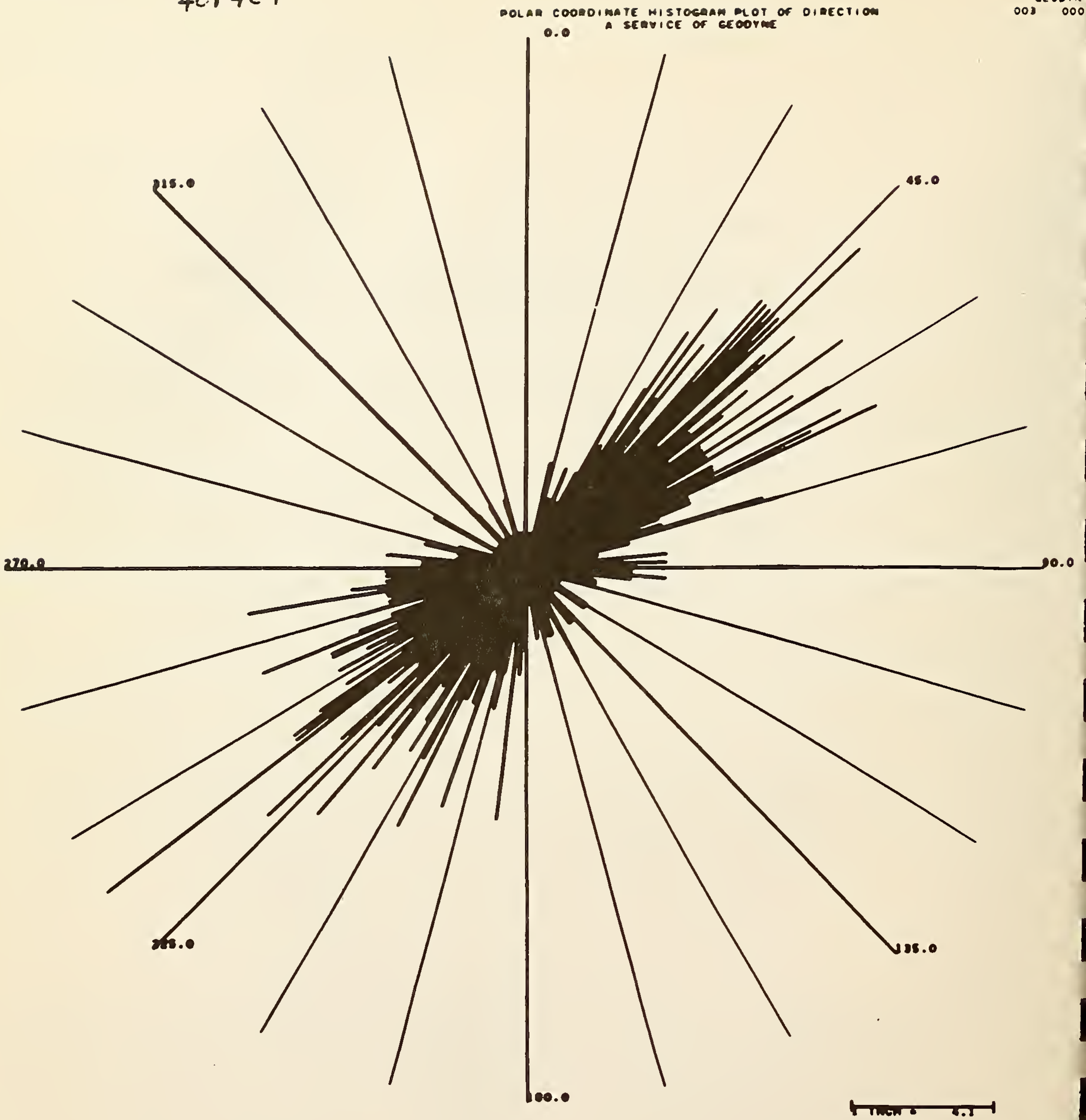


Figure 6a
Mooring A
Direction Histogram

FIGURE 6b

Mooring A, Reference Figure 1 - Legend 4

Speed Histogram in Rectangular Coordinates of the Current Speed at the Entrance to the Western Tributary Tidal Basin

Maximum flows of .5 knots were detected; however, speeds less than .2 knots dominate the data. It is this flow that provides whatever flushing is available for the outfall at the foot of Moore Street.

Figure 6b

Mooring A

Speed Histogram

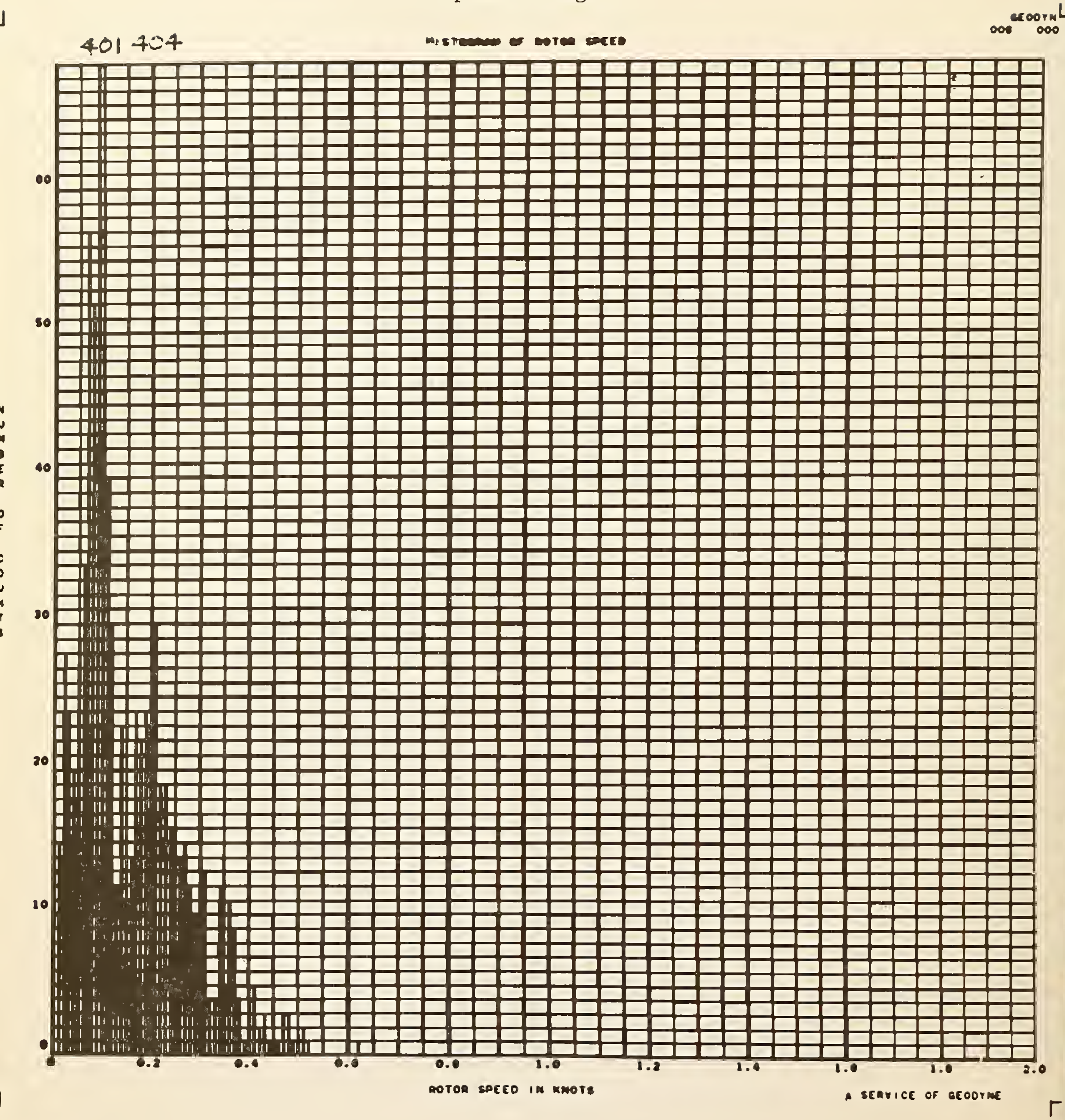


FIGURE 6c

Mooring A, Reference Figure 1 - Legend 4

Scatterplot of Speed Versus Direction for the
Entrance to the Western Tributary Tidal Basin

The data tends not to be as directional as that encountered at Mooring B since the channel effect only takes place for a short period of the tidal cycle. Evidence of its effect is noted in the direction of 45° and 225°. The outgoing speeds tend to be higher as would be expected.

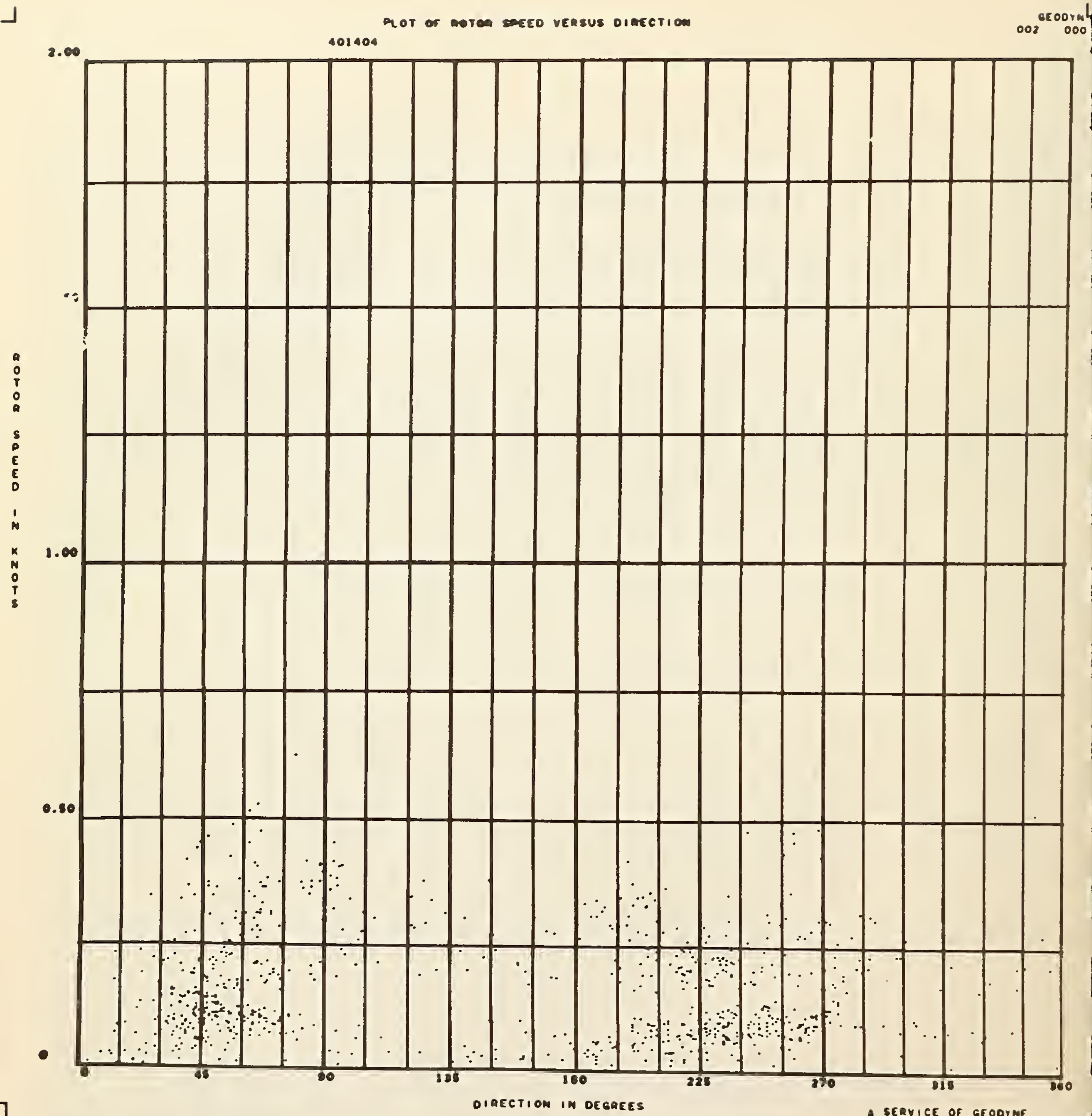


Figure 6c

Mooring A

Scatterplot of Speed Versus Direction

FIGURE 6d

The Progressive Vector for Mooring A at the Entrance to the Western Tributary Tidal Basin

Here, also, we see a record with a much more pronounced variability in the flow patterns. This is undoubtedly due to the physical configuration of this portion of the study area where, at low tide, a narrow channel tends to constrict the flow; but, at high tide, the flow spreads over a much wider region than at the main entrance channel.

Figure 6d
Mooring A
Progressive Vector

FIGURE 7a

Mooring E, Reference Figure 1 - Legend 6

Direction Histogram in Polar Coordinates of the Current Flow at Mooring E, Off Of Orient Heights Beach

Although this data appears to be quite variable in nature, there is a marked tendency for the current to run in the direction 300° or towards the beach.

Figure 7a

Mooring E
Direction Histogram

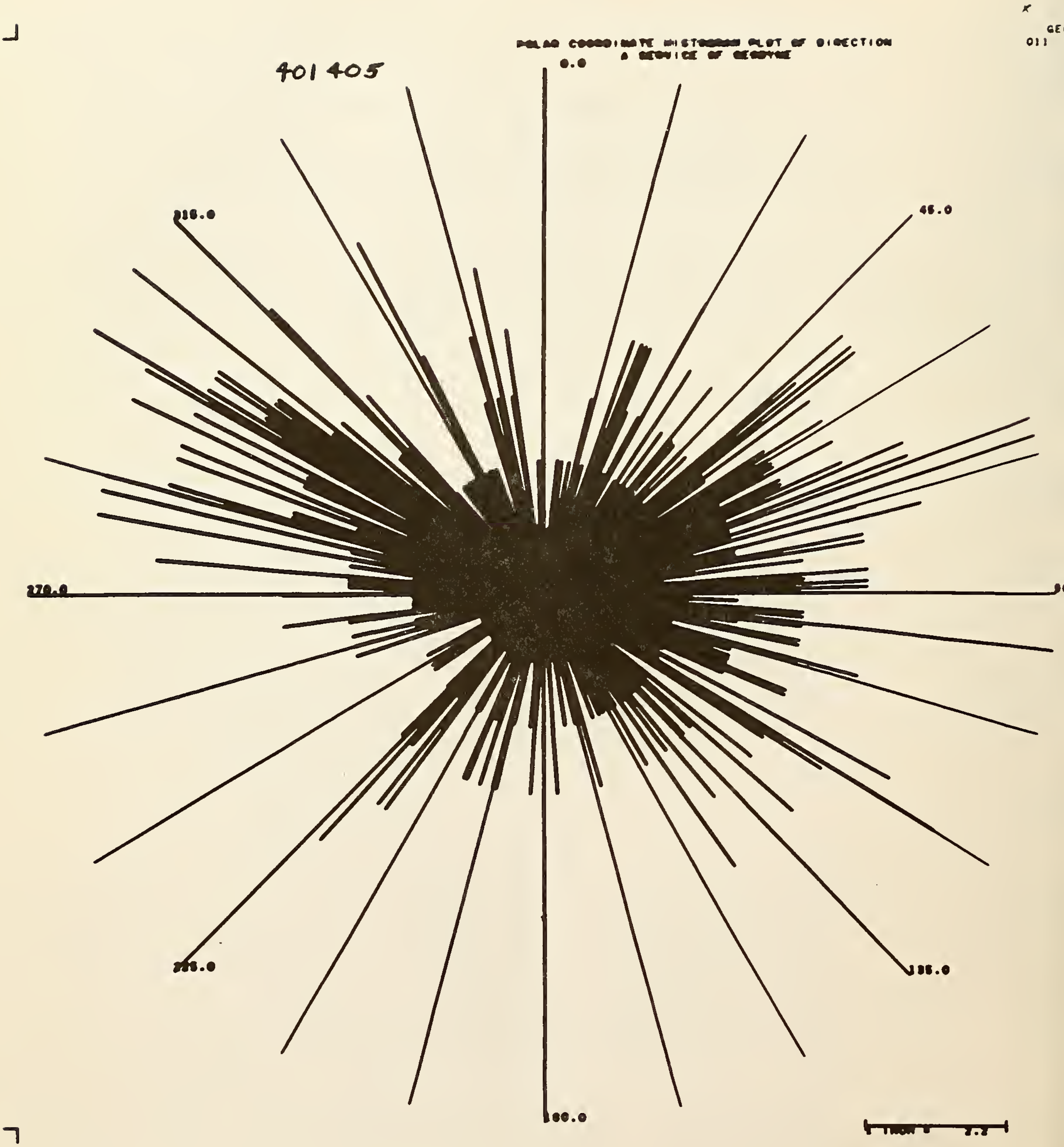


FIGURE 7b

Mooring E, Reference Figure 1 - Legend 6

Speed Histogram in Rectangular Coordinates of the Current Speed
Off of Orient Heights Beach

Current is very weak in this area, with attendant limited dispersion ability.

Figure 7b

Mooring E

Speed Histogram

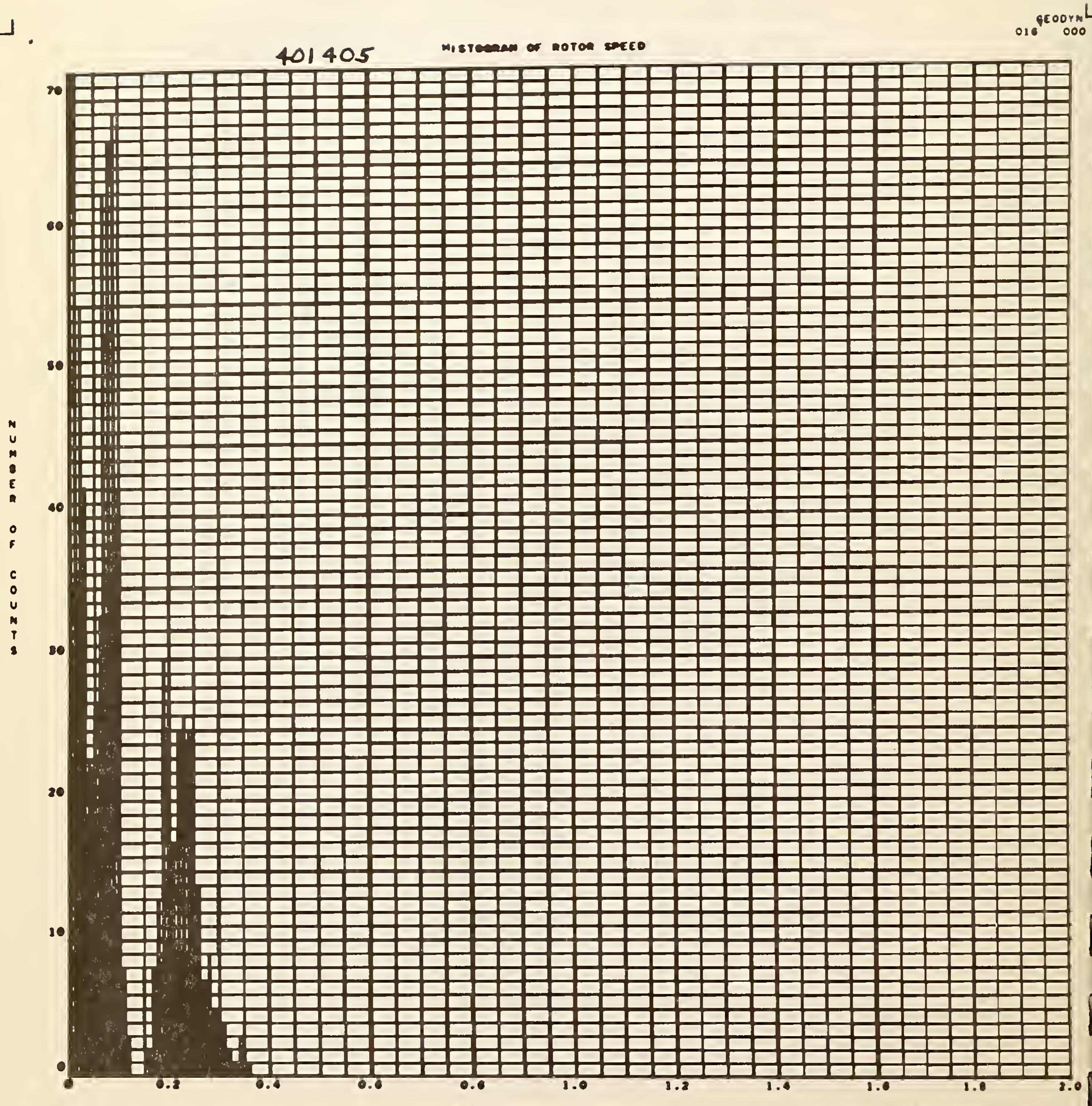


FIGURE 7c

Mooring E, Reference Figure 1 - Legend 6

Scatterplot of Speed Versus Direction for the
Current Mooring Off of Orient Heights Beach

Data is very variable with some tendency to move towards the beach during certain times.

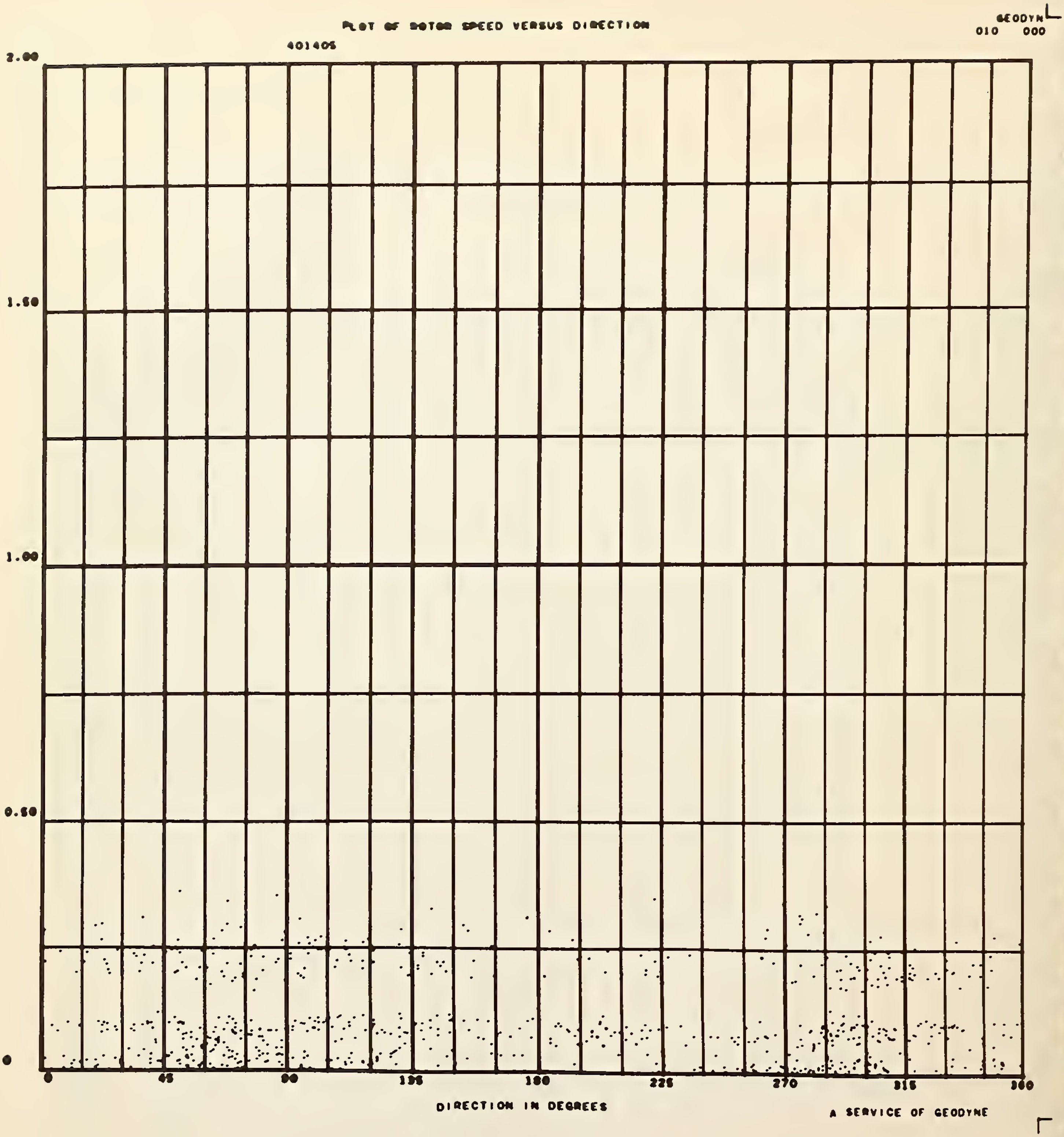


Figure 7c

Mooring E

Scatterplot of Speed Versus Direction

FIGURE 7d

Mooring E - Progressive Vector

The progressive vector for Mooring E, off of Orient Heights Beach shows the most variability of all. It also shows the lowest magnitude of tidal excursions, resulting in unfavorable dispersion of any pollutants which may exist in this region.

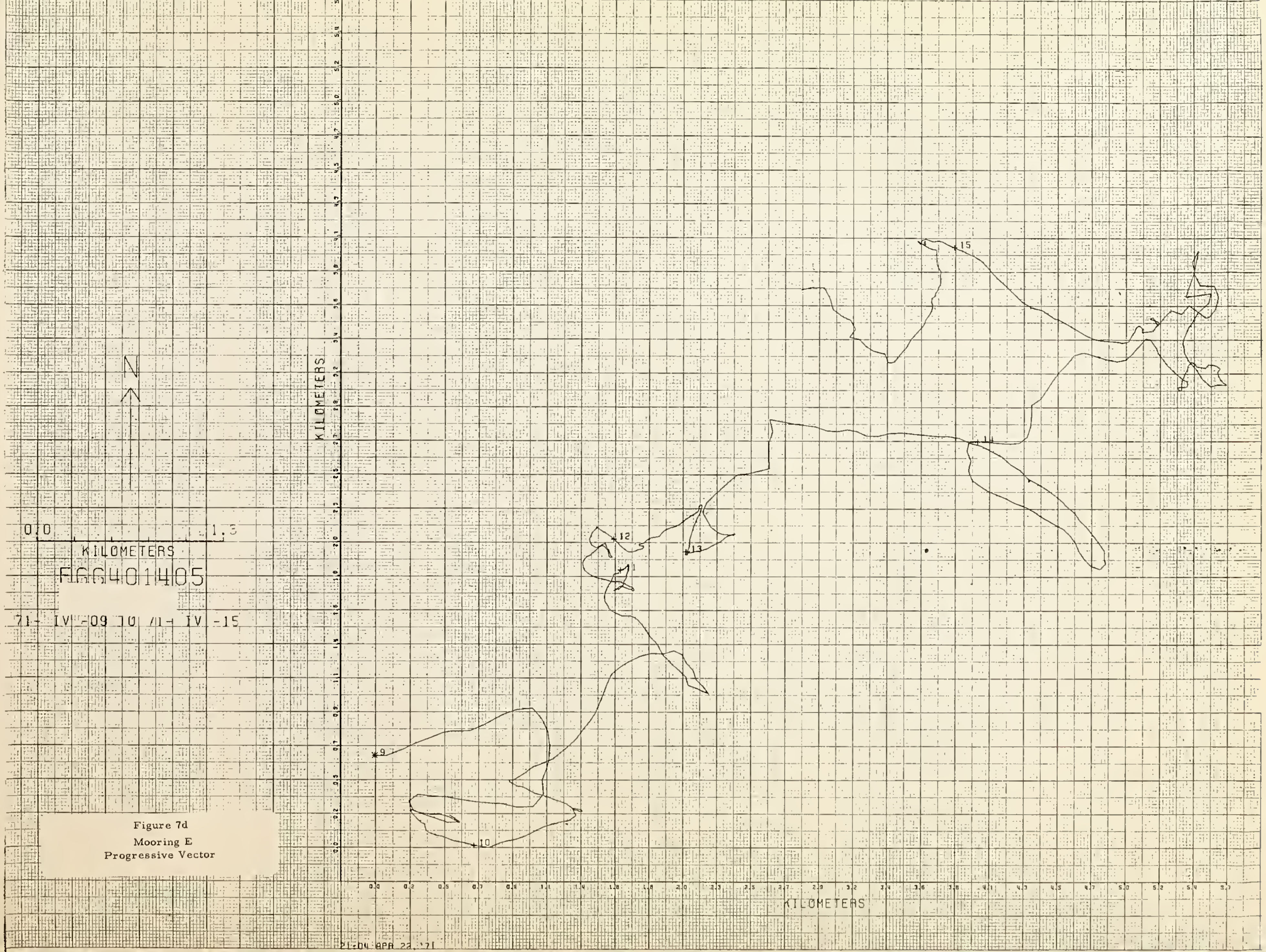


Figure 7d
Mooring E
Progressive Vector

3.2.1.1 Vector Average

The complete listing and plotting of the 10-minute vector averages for each of the current meter records has been forwarded under separate cover.

Figure 8, a reduced xerox reproduction of a portion of one of these records is enclosed for discussion purposes. Each such list and plot is identified by a heading group which contains all of the pertinent identifying data, including latitude, longitude, magnetic variation used to compute true velocity vectors from the magnetic compass reading recorded within the instrument, as well as date and time of origin and the length of the averaging interval, which is here 10 minutes or 600 seconds. Note that, in the listing, not only are the individual averages tabulated numerically for every 10-minute interval (which intervals are identified by day, hours and minutes), but they are also plotted in a pseudographical form by the high-speed printer on the digital computer. Such a listing allows an overall visual examination of the results and for such investigations as the relationship between the current flows and recorded tide data. On the enclosed example, the times of high and low tide are manually superimposed. As can be seen, the time of high water corresponds exactly to the time of the tidal current reversal from flood to ebb. This is as would be expected in such a relatively confined and limited tidal embayment.

3.2.1.2 Composite Vector Plot

Figure 9 is a xerox reproduction of the vector average plots for each current meter for the time period, 10:40 p.m., April 9, 1971, to 11:20 p.m., April 10, 1971. This figure provides a graphic display of the correlation between tides and currents at each station. Direction and speed at all stations are coincident with the tide changes noted on the tide recorder. The entire body of water is operated on by the tide with no appreciable lead or lag at any point, nor is there evidence of other effects.

```
LISPL903
DATE/ 21:04 APR 22,'71


******************
DATA/ EGG401403
******************

FILE CREATED/   15:11 APR 20,'71                                              SOURCE/   06

COMMENT/

LOCATION/   42 22.40 N     70 59.48 W                          MAGNETIC VARIATION/  15 W
DATA TIME ORIGIN/ 71- IV -09  11.00.00.000 Z
  SAMPLES TAKEN EVERY    600.000 SECONDS
************************************************************************************
**** DATA SEQUENCE **** UNITS ***** TYPE * MANF *** INST *** DEPTH M  ** BIAS VALUE ****
************************************************************************************
**(1) COMPASS      * 128.LVL.BIN  *  B   *  02  *         *     0.00 *             0
**(2) VANE         * 128.LVL.BIN  *  B   *  02  *         *     0.00 *             0
**(3) DIRECTION    * 128.LVL.BIN  *  B   *  02  *         *     0.00 *             0
**(4) SPEED        * MM/SEC       *  H   *  02  *         *     2.10 *             0
**(5) TIME         * MS           *  T   *  02  *         *     0.00 *             0
**(6) COMPASS NUV  * NON-DIM      *  R   *  02  *         *     0.00 *  0.00000
**(7) VANE NUV     * NON-DIM      *  R   *  02  *         *     0.00 *  0.00000
**(8) DIRECTION    * DEGREES      *  H   *  02  *         *     0.00 *             0
**(9) INCLINOMETER *  DEGREES     *  H   *  02  *         *     0.00 *             0
```

Figure 8 - Vector Averages for Current Meter Records

High Tide
2245

LOW TIDE
0450

25	92010	242
20	92020	159
0	92030	164
8	92040	169
335	92050	46
17	92100	46
37	92110	283
37	92120	216
34	92130	154
34	92140	149
39	92150	149
37	92200	108
45	92210	72
51	92220	51
93	92230	20
295	92240	41
278	92250	128
236	92300	139
245	92310	154
242	92320	159
245	92330	200
248	92340	190
262	92350	221
262	100000	221
259	100010	216
259	100020	226
259	100030	236
259	100040	252
256	100050	252
242	100100	247
200	100110	231
208	100120	226
214	100130	236
214	100140	231
231	100150	200
236	100200	190
250	100210	200
233	100220	195
225	100230	190
208	100240	195
200	100250	195
211	100300	200
211	100310	190
200	100320	185
205	100330	164
211	100340	139
233	100350	41
259	100400	61
259	100410	36
231	100420	30
236	100430	30
281	100440	10
11	100450	25
8	100500	30
23	100510	25
45	100520	30
51	100530	77
45	100540	123
42	100550	159
45	100600	200
37	100610	200
31	100620	175
39	100630	200
42	100640	247
37	100650	272
42	100700	272

37	100730	330
39	100740	329
25	100750	252
28	100800	242
34	100810	339
45	100820	324
45	100830	427
42	100840	427
34	100850	370
39	100900	417
39	100910	355
42	100920	355
39	100930	344
39	100940	267
37	100950	200
34	101000	123
31	101010	77
31	101020	77
39	101030	66
62	101040	15
155	101050	10
169	101100	13
191	101110	20
143	101120	15
130	101130	30
231	101140	41
253	101150	72
253	101200	139
253	101210	149
250	101220	154
242	101230	154
242	101240	169
246	101250	195
245	101300	211
242	101310	205
242	101320	180
239	101330	169
236	101340	180
236	101350	190
242	101400	303
242	101410	344
250	101420	391
219	101430	355
208	101440	360
211	101450	324
203	101500	308
205	101510	283
211	101520	283
214	101530	272
208	101540	278
217	101550	257
225	101600	253
231	101610	257
219	101620	319
228	101630	303
245	101640	303
301	101650	272
3	101700	262
25	101710	257
45	101720	242
39	101730	242
37	101740	257
39	101750	226
37	101800	236

High Tide
1100

LOW TIDE
1700

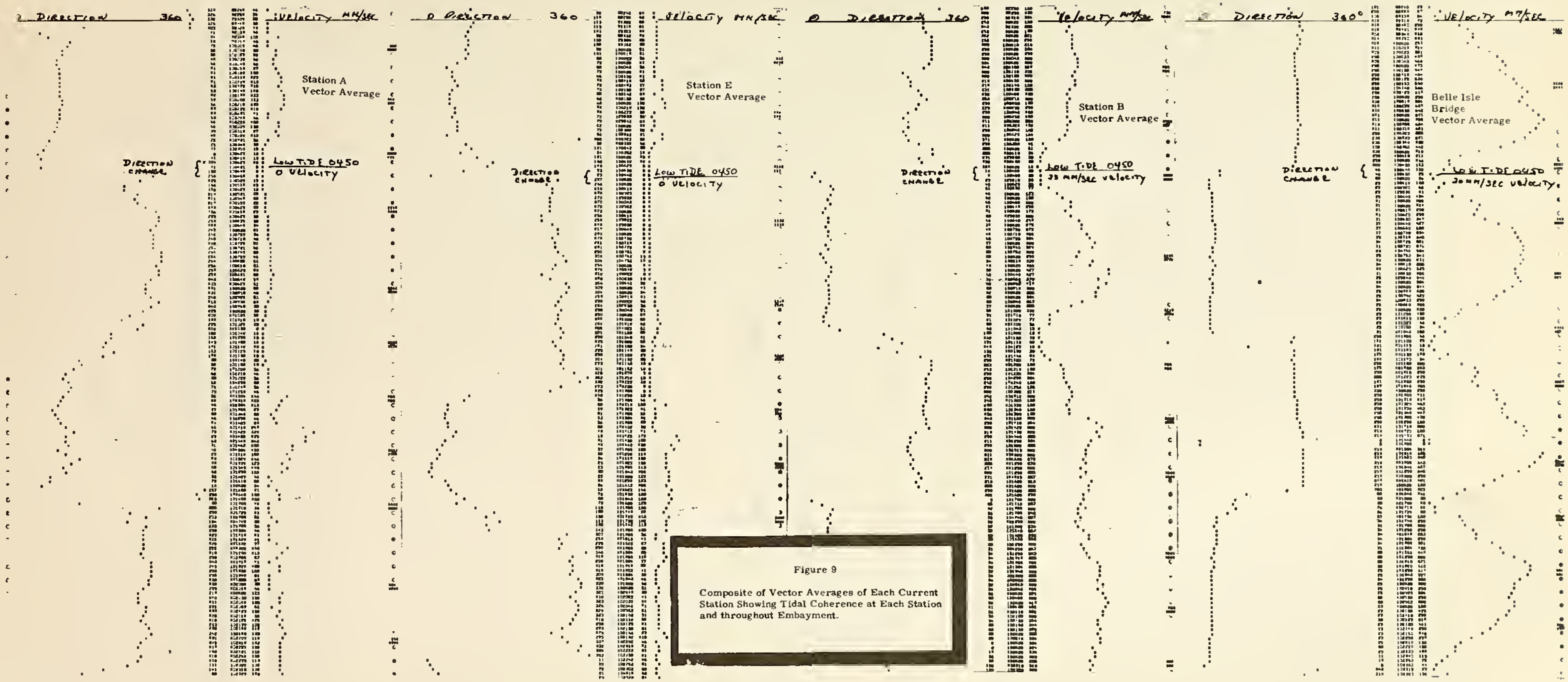


Figure 9

Composite of Vector Averages of Each Current Station Showing Tidal Coherence at Each Station and throughout Embayment.

3.2.2 Drogue Data

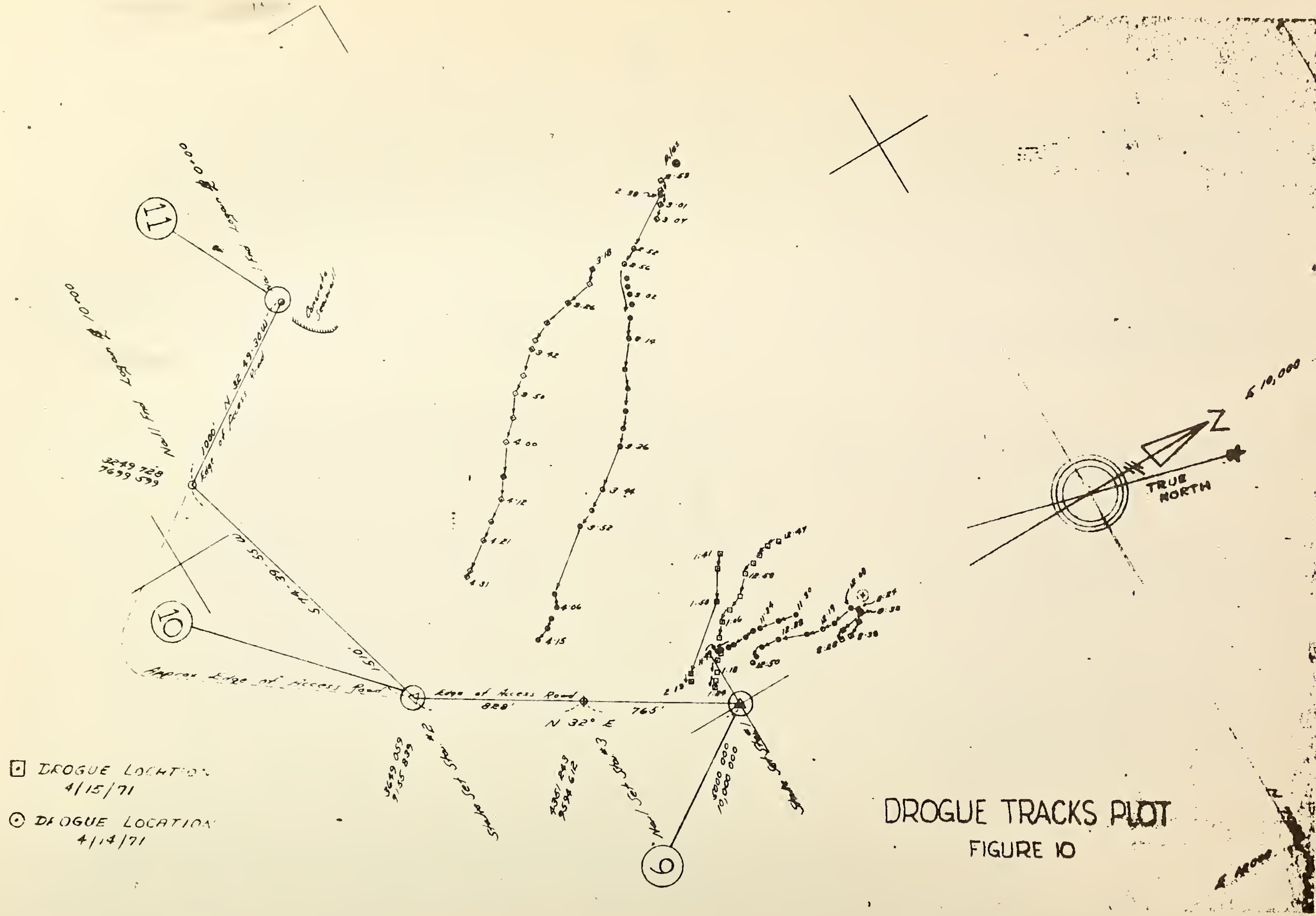
In order to describe the surface current patterns in and out of the West Tributary Tidal Basin, a drogue study was conducted, and the following data recorded as discussed herein.

The data for the drogue track is plotted on Figure 10, which is the same scale as Figure 1 and may be used as an overlay to provide a scale pictorial representation of the drogue tracks. It is evident that each drogue set had a tendency to proceed in a south-southeasterly direction whether the tide was flooding or ebbing. This is due in large part to the wind conditions which were prevelant during the period of the study. During the drogue field work, many of the drogues actually stopped their track on the airport shore which is indicative of the pattern to be followed by the fresher water being discharged from the combined sewer outfall at the end of Moore Street. It is also clear from the drogue study that winds of 15 to 30 knots out of the northwest will have significant mixing effect and that the proposed fill will reduce that mixing effect considerably by reducing the fetch in the southeasterly and northwesterly directions.

Drogue data has been tabulated for each track and is presented in Figure 11. Each tabulation presents time, position, north and east velocity components, computed velocity in knots and the direction in degrees. In addition, average velocity and direction computations have been made. It should be noted that the average maximum speed recorded, even with relatively strong winds, did not exceed .5 knots and that the predominate speed was about .25 knots.

3.2.3 Tides

Tide records were obtained to aid in computation of tidal prism. Tide tables for the period of the survey are presented in Figure 12. A portion of the actual tide record is enclosed in Figure 13. This tide data and the expanded time scale on the tidal record insured against overlooking some unexpected



DROGUE TRACKS PLOT

FIGURE 10

Figure 11 - Drogue Data Tabulation

Date - April 14, 1971 Tide Rising Start Vicinity of Mooring "A"

TIME HRS:MIN	POSITION (FEET) NORTH	EAST	VELOCITY COMP. VN	VE	VELOCITY KNOTS	DIRECTION DEGREES	Average Velocity & Direction	
L = 43								
N = 51								
11:30	5459.4	9765.4	0.00	0.00	0.00	0.00		
11:32	5374.4	9745.6	-0.42	-0.10	0.43	192.99		
11:34	5276.5	9730.1	-0.48	-0.08	0.49	189.11		
11:36	[illegible].9	9725.1	-0.18	-0.02	0.18	167.72		
11:38	5167.3	9730.4	-0.26	0.03	0.26	174.21		
11:[illegible]	5119.7	9726.5	-0.17	-0.00	0.17	161.61		
11:44	5096.4	9729.4	-0.12	0.00	0.12	177.92		
11:46	5057.1	9725.7	-0.19	-0.02	0.19	1[illegible]5.43		
11:49	5042.2	9720.0	-0.05	-0.02	0.05	250.62		
L = 52							.24	185°
N = 59								
12: 8	5714.2	9874.5	0.00	0.00	0.00	0.00		
12:15	[illegible]	9894.5	-0.15	0.03	0.16	17[illegible]		
12:19	5537.4	9888.6	-0.15	-0.01	0.16	184.70		
12:22	5461.0	9869.7	-0.25	-0.06	0.26	193.92		
12:28	5323.6	9823.0	-0.23	-0.08	0.24	198.77		
12:36	5233.2	9814.7	-0.11	-0.01	0.11	185.23		
12:4[illegible]	5167.1	9837.4	-0.05	0.04	0.08	153.70		
12:[illegible]	5161.5	9855.9	-0.03	0.02	0.04	145.29		

Date - April 14, 1971 Tide Ebbing Start Vicinity of Outfall .15 175°

TIME HRS:MIN	POSITION (FEET) NORTH	EAST	VELOCITY COMP. VN	VE	VELOCITY KNOTS	DIRECTION DEGREES	Average Velocity & Direction	
L = 1								
N = 22								
2:35	5960.2	7669.1	0.00	0.00	0.00	0.00		
2:52	5708.0	7821.2	-0.18	0.11	0.21	147.43		
2:56	5625.5	786[illegible].6	-0.20	0.10	0.22	153.59		
2:59	5604.0	7924.2	-0.08	0.21	0.22	111.20		
3: 0	5592.3	7960.2	-0.11	0.36	0.37	107.65		
3: 2	5573.7	8000.5	-0.09	0.20	0.22	114.67		
3: 5	5557.6	8045.3	-0.05	0.15	0.16	109.72		
3:11	5513.2	8094.9	-0.07	0.08	0.11	130.54		
3:14	5216.0	8126.9	-0.99	0.10	0.99	174.07		
3:20	5362.4	8305.4	0.24	0.29	0.38	50.77		
3:25	5327.7	8390.6	-0.07	0.17	0.18	112.17		
3:29	5269.0	8479.1	-0.17	0.22	0.27	127.38		
3:32	5209.0	8545.4	-0.17	0.22	0.28	127.63		
3:36	5149.9	8609.4	-0.15	0.16	0.21	132.70		
3:44	4968.7	8747.8	-0.22	0.17	0.28	142.63		
3:47	4878.1	8813.9	-0.30	0.22	0.37	143.88		
3:52	4791.2	8849.4	-0.17	0.07	0.19	157.79		
4: 3	4497.1	9066.2	-0.26	0.19	0.33	143.61		
4: 6	4478.9	9127.5	-0.06	0.20	0.21	106.50		
4: 9	4437.3	9156.4	-0.14	0.09	0.17	145.25		
4:12	4381.8	9196.5	-0.18	0.13	0.23	144.10		
4:15	4312.0	9218.1	-0.23	0.07	0.24	162.87	.23	127°

Figure 11 - Drogue Data Tabulation

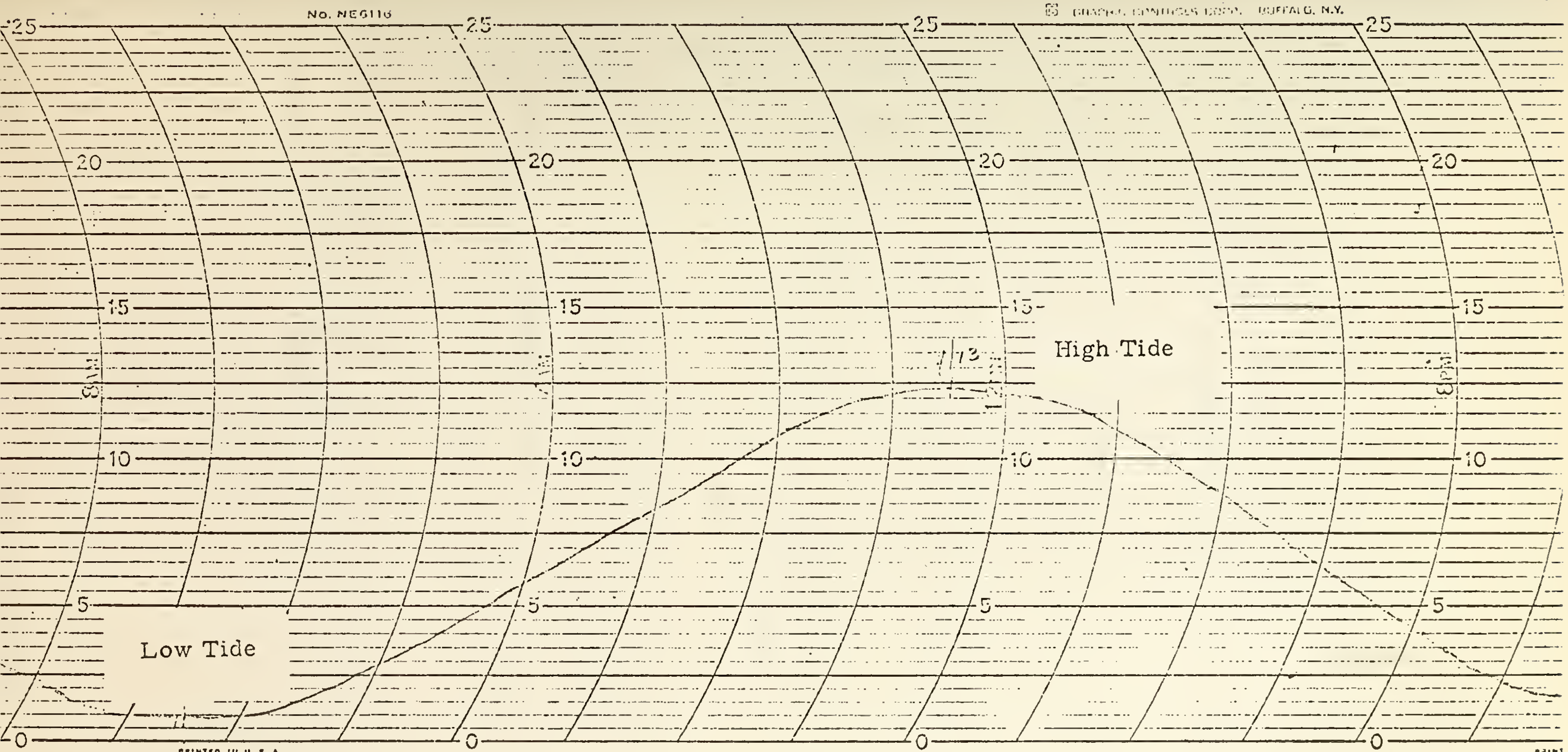
							Average Velocity & Direct	
L = 60								
N = 62	Date - April 15, 1971	Tide Rising	Start Vicinity of Mooring "A"					
8:24	5735.3	9991.5	0.00	0.00	0.00	0.00		
8:26	5710.2	9959.8	-0.12	0.24	0.27	116.93		
8:28	5638.6	9992.5	-0.35	0.21	0.41	149.80		
L = 63							.34	132°
N = 65								
8:33	5739.9	9892.5	0.00	0.00	0.00	0.00		
8:36	5616.8	9944.9	-0.40	0.17	0.44	156.96		
8:38	5592.6	9986.3	-0.12	0.20	0.24	120.36		
L = 66							.34	138°
N = 68								
8:44	5746.5	99[illegible].4	0.00	0.00	0.00	0.00		
8:46	5692.0	9952.1	-0.27	0.25	0.37	136.56		
8:49	[illegible]	[illegible]	-[illegible]	0.15	0.27	144.44		
L = 69							.32	140°
N = 71								
9:13	5728.3	9877.5	0.00	0.00	0.00	0.00		
9:16	5563.2	9915.[illegible]	-[illegible].21	0.13	[illegible].25	145.32		
9:1[illegible]	[illegible].7	[illegible].8	-[illegible].51	[illegible]	[illegible].55	157.25		
L = 72							.40	153
N = 74								
9:23	5834.7	9792.5	0.00	0.00	0.00	0.00		
9:26	5654.3	9864.8	-[illegible]9	0.24	0.55	154.23		
9:2[illegible]	[illegible].5	9911.9	-[illegible].38	0.23	[illegible]	14[illegible]		
L = 75							.50	151
N = 77								
9:3[illegible]	[illegible].1	97[illegible].2	[illegible]	[illegible]	[illegible]	[illegible]		
9:[illegible]	[illegible]	[illegible].6	-[illegible]	0.19	[illegible]	157.1[illegible]		
9:42	5551.5	9856.5	-0.15	0.11	0.15	14[illegible]		
N = 80							.24	150
9:47	5668.8	964[illegible].0	0.00	0.00	0.00	0.00		
9:50	5648.5	9659.1	-0.07	0.06	0.09	137.51		
9:5[illegible]	5592.7	[illegible]	-[illegible].27	[illegible]	0.34	14[illegible]		
9:5[illegible]	[illegible]	975[illegible].5	-[illegible]	.1[illegible]	[illegible].25	1[illegible]		
	Date - April 15, 1971	Tide Ebbing	Start Vicinity of Outfall				.22	144
2:53	5993.1	7655.9	0.00	0.00	0.00	0.00		
2:56	5971.4	7646.5	-0.07	0.13	0.15	117.39		
3: 1	59[illegible].5	77[illegible]	-[illegible]	0.11	[illegible].15	1[illegible]		
3: 7	[illegible]	77[illegible].5	[illegible]	[illegible]	0.12	135.4[illegible]		
>00 [illegible] 1							.13	125
L = 27								
N = 40	Date - April 15, 1971	Tide Ebbing	Start Vicinity of Outfall					
3:1[illegible]	[illegible]	72[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
3:22	5428.3	7759.1	-0.12	0.14	0.16	132.44		
3:26	5291.2	7834.4	-0.34	0.[illegible]6	0.34	162.50		
3:34	51[illegible].8	791[illegible]	-0.17	0.03	0.18	166.36		
3:38	5057.0	7953.0	-0.23	0.19	0.25	158.43		
3:42	5020.6	7960.5	-0.09	0.08	0.12	139.92		
3:46	4921.9	8060.0	-0.24	0.21	0.32	139.43		
3:50	4840.8	8124.7	-0.20	0.14	0.24	145.06		
3:55	4773.4	8222.1	-0.13	0.19	0.23	124.63		
4: 0	4681.7	8311.1	-0.18	0.18	0.25	135.85		
4: 5	4581.3	844[illegible].3	-0.30	0.27	0.04	126.13		
4:12	4514.7	8543.2	-0.09	0.13	0.16	125.12		
4:13	4415.9	8604.6	-0.98	0.61	1.15	143.17		
4:21	4338.4	8666.2	-0.10	0.08	0.12	141.51		
4:28	4197.3	8761.2	-0.20	0.13	0.24	146.11		
4:31	4175.4	8774.5	-0.07	0.04	0.08	148.52		
>00 PART29:-							.21	14

Figure 12

TIDE DATA

Date	Time	Tide	Range	Calibration* -1.4	Actual Range
4/9/71	10:45 p.m.	12.2'			
4/10/71	4:50 a.m.	1.5'	10.7'		9.3'
4/10/71	11:00 a.m.	11.5'	10.0'		8.6'
4/10/71	5:00 p.m.	1.0'	10.5'		9.1'
4/10/71	11:22 p.m.	11.7'	10.7'		9.3'
4/11/71	5:20 a.m.	.5'	11.2'		9.8'
4/11/71	11:45 a.m.	11.3'	10.8'		9.4'
4/11/71	5:40 p.m.	1.0'	10.3'		8.9'
4/11/71	11:54 p.m.	11.8'	10.8'		9.4'
4/12/71	5:55 a.m.	-.5'	12.3'		10.9'
4/12/71	12:18 p.m.	10.9'	11.4'		10.0'
4/12/71	6:05 p.m.	1.2'	9.7'		8.3'
4/13/71	12:30 a.m.	11.8'	10.6'		9.2'
4/13/71	6:30 a.m.	0.0'	11.8'		10.4'
4/13/71	1:04 p.m.	10.9'	10.9'		9.5'
4/13/71	6:43 p.m.	1.0'	9.9'		8.5'
4/14/71	1:15 a.m.	12.2'	11.2'		9.8'
4/14/71	7:20 a.m.	.4'	11.8'		10.4'
4/14/71	1:30 p.m.	10.8'	10.4'		9.0'
4/14/71	7:40 p.m.	1.1'	9.7'		8.3'
4/15/71	1:46 a.m.	11.7'	10.6'		9.2'
4/15/71	8:00 a.m.	-.2'	11.9'		10.5'
4/15/71	2:20 p.m.	10.0'	10.2'		8.8'

*(Represents calibration of tide recorder before and after Survey.)



Tide Record from 7:00 p.m., April 12, 1971, through 8:00 a.m., April 13, 1971

Tide Low at 6:05 p.m., April 12, 1971
Tide High at 12:30 a.m., April 13, 1971
Tide Low at 6:30 a.m., April 13, 1971

Figure 13

tidal anomaly which might effect mixing processes in these embayments. However, as mentioned later, extremely regular and coherent tidal heights and tidal currents were found. Correlation with the tide data published by the National Oceanographic and Atmospheric Agency, National Ocean Survey for Boston Harbor was excellent with no significant leads or lags noted.

3.2.4 Wind

Figure 14 tabulates the wind direction and velocity as recorded at Logan International Airport from 0630-1930 on April 14, 1971, and April 15, 1971. The conditions both days were similar with the wind out of the northwest having gusts up to 30 knots. The resulting effects on the surface water of the Western Tributary Tidal Basin were quite dramatic. The drogues were tracked as moving southeasterly throughout the period. The wind effects on the Western Tributary Tidal Basin are important. Since water depths are shallow, it may be assumed that mixing under persistent winds will differ greatly over the low or gentle wind condition.

3.2.5 Bathymetry

Depth profiles were made from the survey vessel using a Bludworth depth sounder. Each area of interest was profiled to aid in mass balance calculations. Figure 15 is a copy of the profile record with each mooring depth and the channel profiles at the entrance to the Main Tidal Basin and Western Tributary Tidal Basin annotated. Figure 16 denotes the depths at the moorings.

3.2.6 Mass Balance

The mass balance of the Main Tidal Basin and the Western Tributary Tidal Basin was determined by two methods in order to quantify the tidal prism and provide a basis upon which the effects of the proposed fill could be assessed with respect to the computer predictive models.

Figure 14

WIND DIRECTION AND VELOCITY

RECORDED AT LOGAN INTERNATIONAL AIRPORT

April 14, 1971

Time	Direction	Velocity Knots	Gust
0630	240°	10	
0700	250°	10	
0730	250°	10	
0800	300°	09	
0830	300°	14	
0900	300°	14	
0930	300°	14	
1000	320°	12	
1030	320°	18	
1100	320°	14	
1130	310°	14	
1200	320°	16	
1230	290° (variable)	18	
1300	320°	17	
1330	320°	16	
1400	310°	15	
1430	320°	20	25
1500	330°	17	
1530	320°	15	
1600	320°	17	24
1630	320°	15	23
1700	320°	16	23
1730	320°	16	
1800	310°	14	
1830	310°	15	26
1900	310°	18	26
1930	320°	18	22

Figure 14

WIND DIRECTION AND VELOCITY

RECORDED AT LOGAN INTERNATIONAL AIRPORT

April 15, 1971

Time	Direction	Velocity Knots	Gust
0630	300°	13	
0700	300°	18	
0730	300°	13	
0800	300°	13	
0830	340°	16	
0900	310°	13	
0930	310°	14	
1000	330°	17	
1030	330°	15	
1100	330°	14	
1130	320°	20	
1200	310°	20	29
1230	310°	20	25
1300	310°	20	26
1330	310°	22	26
1400	310°	16	29
1430	310°	18	26
1500	310°	19	28
1530	350°	23	28
1600	320°	20	30
1630	350°	20	30
1700	310°	14	23
1730	340°	18	20
1800	340°	12	21
1830	340°	14	22
1900	320°	16	23
1930	350°	10	

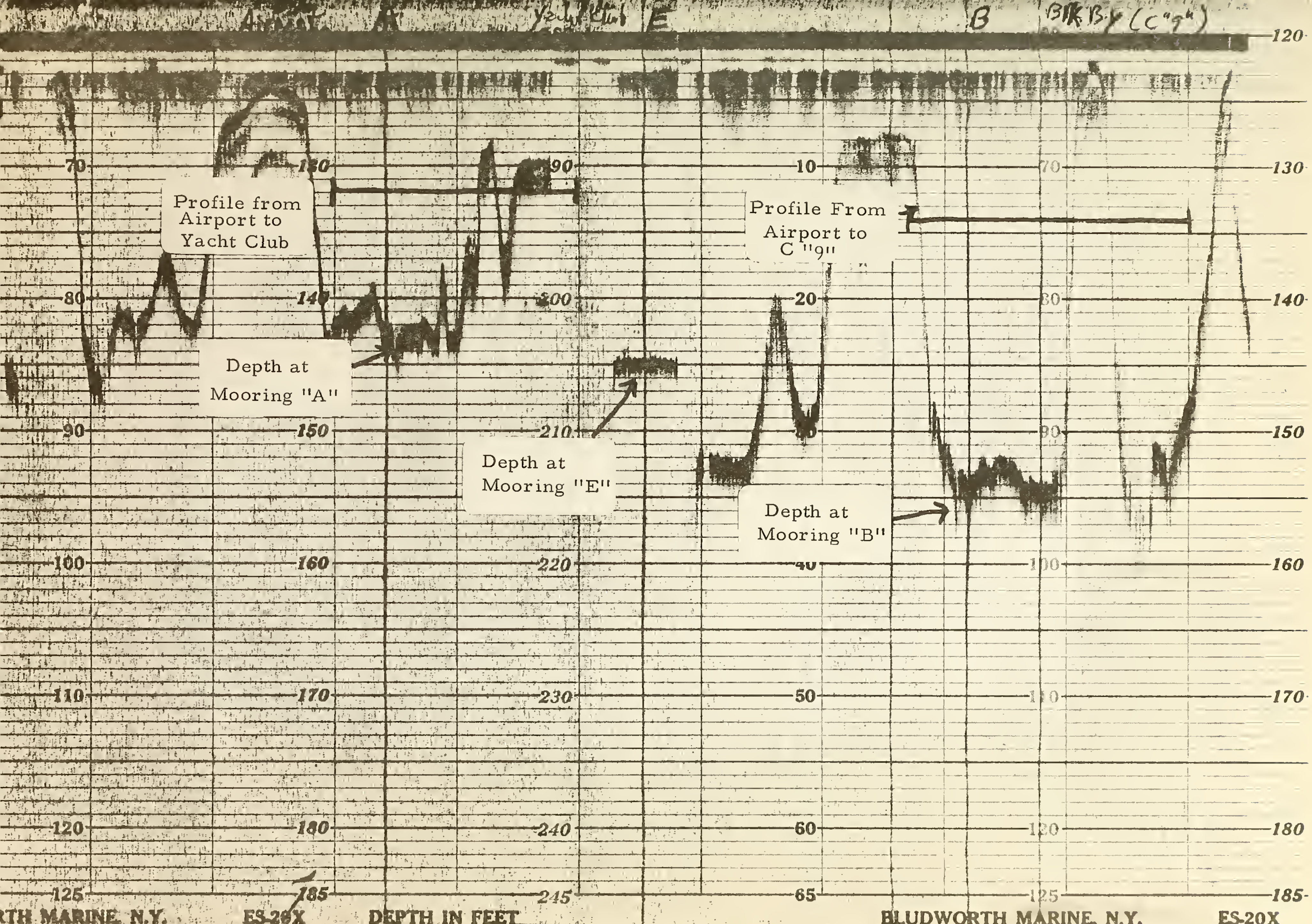


Figure 15 - Bathymetric Record

Figure 16

BATHYMETRY TABLE

	Sounding	Height of Tide Above MLW	Depth @ MLW
Mooring "A"	22'	5.0'	17.0'
Mooring "B"	33'	5.4'	27.6'
Mooring "E"	25'	5.2'	19.8'

The initial calculation of mass balance was accomplished by planimetering the area of the Main Tidal Basin (Figure 1 - Legend 1), the Western Tributary Tidal Basin (Figure 1 - Legend 2), and the proposed fill area (Figure 1 - Legend 3). These areas were then multiplied by the average tide range of 9 feet, which was chosen to represent worst-case conditions.

The resulting volumes, based on the above formula, are:

Main Tidal Basin	202.8×10^4 cubic meters
Western Tributary Tidal Basin	171.0×10^4 cubic meters
Proposed Fill	57.3×10^4 cubic meters

Total volume of the tidal prism in the Main Tidal Basin and Western Tributary Tidal Basin = $202.8 \times 10^4 + 171.0 \times 10^4 = 373.8 \times 10^4$ cubic meters.

These calculations were then verified by utilizing the bathymetric data obtained during the survey and the current meter data to compute the net volume moving in and out of the Western Tributary Tidal Basin and the combination of the Western Tributary Tidal Basin and the Main Tidal Basin.

<u>Volume Exchange at Mooring A, the Entrance to the Western Tributary Tidal Basin</u>

Width of Channel	125 yards
Average Depth	7 yards
Cross Section Area	733 m^2
Average Maximum Flow	13.9 cm/sec
Average Maximum Flow x $2/\pi$ = Mean Velocity	8.85 cm/sec
Mean Flow x Area x Tidal Cycle = Volume Exchange	140.8×10^4 cubic meters

This compares favorably with the calculation of 171.0×10^4 cubic meters volume arrived at above.

For purposes of this report, we have averaged the two calculations and arrived at: Volume exchange for Western Tributary Tidal Basin = 155.0×10^4 cubic meters.

The proposed fill area (Figure 1 - Legend 3) will decrease the total volume exchange in the Western Tributary Tidal Basin as follows:

Volume Exchange of Western Tributary Tidal Basin	155.0×10^4 cubic meters
Volume Exchange of Proposed Fill	57.3×10^4 cubic meters
Net Exchange	97.7×10^4 cubic meters

This is a 37% reduction in exchange.

Further verification of the calculations were made by computing the volume exchange at Mooring B, the entrance to the Main Tidal Basin, subtracting the loss in volume exchange through Belle Isle Inlet. This figure should compare with the total volume exchange of the Western and Main Tidal Basins.

Volume Exchange at Mooring B

Width of Channel	130 yards
Average Depth	10.7 yards
Cross Section Area	1160 m^2
Average Maximum Flow	38.5 cm/sec
Average Maximum Flow x $2/\pi$ = Mean Velocity	24.5 cm/sec
Mean Flow x Area x Tidal Cycle = Volume Exchange	613.5×10^4 cubic meters

Volume Exchange at Belle Isle Inlet

Width of Channel	70 yards
Average Depth	3.5 yards
Cross Section Area	204 m^2
Average Maximum Flow	57.3 cm/sec
Average Maximum Flow x $2/\pi$ = Mean Velocity	36.5 cm/sec
Mean Flow x Area x Tidal Cycle = Volume Exchange	160.9×10^4 cubic meters

Therefore, volume exchange at Mooring B, less the volume exchange at Belle Isle Inlet, equals total volume exchange for the Western and Main Tidal Basins.

Volume Exchange at Mooring B	613.5×10^4 cubic meters
Volume Exchange at Belle Isle Inlet	160.9×10^4 cubic meters
Volume Exchange for Western Tributary Tidal Basin and Main Tidal Basin	452.6×10^4 cubic meters

From above, volume exchange for the Western Tributary Tidal Basin and the Main Tidal Basin = 373.8×10^4 cubic meters.

There is agreement within 12%.

The data discussed in the preceding paragraphs provides an excellent base for computer modeling techniques which are discussed in the next section.

The baseline conditions for the areas of the Western and Main Tidal Basins can be summarized as follows:

The combined bodies of water represent a tidal embayment whose current flow is characteristically due to the rise and fall of the tide with speed variations due to the bottom topography of the particular site. The entire system oscillates in synchronism with the tides of Boston Harbor. Surface wind effects, especially in the northwest and southeast direction, will have significant effects on surface current in the Western Tributary Tidal Basin.

The variability of the currents off of the Orient Heights Beach and their very low speeds indicate that there is not adequate flushing in the area to provide adequate diffusion and dispersion of pollutants from the sewer at the foot of Moore Street.

It should also be noted that the depths at MLW, noted on National Ocean Survey Chart No. 248, are based on 1946 soundings and some changes have occurred which have made both bodies of water (the Main Tidal Basin and the Western Tributary Tidal Basin) much shallower at MLW.

SECTION 4.0 COMPUTER PREDICTIVE MODELING

Predictive modeling computations were performed on two current meter records from Stations A and E; that is to say, from those records most directly associated with the sewer outfall and the proposed land fill. The techniques employed in this were developed by M. D. Palmer and J. B. Izatt, of the Ontario Water Resources Commission, Toronto, Ontario, Canada. These techniques have been reported in the literature in a number of papers, copies of which are enclosed herewith in Appendix I. These are as follows:

> "Lake Hourly Dispersion Estimates from a Recording Current Meter," Vol. 76, No. 3, Journal Geophysical Research, January 20, 1971.
>
> "Lakeshore Two-Dimensional Dispersion," Proceedings of the 13th Conference on Great Lakes Research, 1970.
>
> "Dispersion Predictions from Current Meters," Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, August, 1970.

All of this work was carried out on an IBM 360 installation, the current meter data having been transferred to a suitable tape format as discussed in Appendix I. Each of these procedures builds upon the previous and the entire approach will be discussed as a unit with reference to suitable portions of the above papers as is appropriate.

Having transferred the 10-minute vector average data to the IBM 360 format, the time series is smoothed to remove sharp transients which would seriously distort the analysis. This is a very simple operation involving the successive computations of a moving average of eleven (11) values and the substitution of this average value for the sixth value in each of the sets of eleven. Using the smoothed data, a frequency table is generated, which is a

two-dimensional matrix having 20 speed-range categories and 24 15° direction categories. These two tables are presented (each in two parts; therefore, requiring four pages in all) as Figure 17. Note that these figures are numerical representations in quantitative form of the same information contained in the direction histogram, presented in Figures 4a, 5a, 6a, and 7a of this report. The 15° direction increments are centered in such a way that they include the cardinal points of the compass. The speed ranges are, except for the first and second ranges, which are from 0 to 0.3 and .31 to 2.99 centimeters per second, 3 centimeters per second wide. A look at this figure tells one a great deal about the performance of the currents in these particular areas. However, they are included here only for background data, for this information is used by subsequent steps in the analysis.

In addition to the table, there was also computed, at this point, a resultant current, resultant components and a resultant direction. Here again, it must be noted that the number of tidal cycles will directly effect the value of these figures. This data is listed at the bottom of the second page of the Frequency Table. Other figures given here which are even more valuable include the average speed, the persistence* (which is very low and, thus, indicative of the fact that this is an oscillatory regime) and the maximum speed along with the number of readings and the duration of the readings.

Note that, since all the data contained in this report has been reduced in the metric system, it is probably of value to note that 50 centimeters per second is 1 knot.

Further preparatory computations include the following, based on the development of the Frequency Table. These are the auto-correlation coefficients computed for both Stations A and E and the cross-correlation coefficients

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*Persistence is a measure of the uniformity of flow; i. e., a river has a persistence of 1, a completely random body of water would be 0.

FREQUENCY ANALYSIS FOR CURRENT METER OATA

STATION A

DIRECTION(IN OEGREES)

SPEEO(CM/SEC)	352.5- 7.49	7.50- 22.49	22.50- 37.49	37.50- 52.49	52.50- 67.49	67.50- 82.49	82.50- 97.49	97.50- 112.49	112.50- 127.49	127.50- 142.49	142.50- 157.49	157.50- 172.49
0.00- 0.30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.31- 2.99	0.116	0.232	0.695	0.463	0.579	0.463	0.579	0.695	0.579	0.348	0.695	0.695
3.00- 5.99	0.232	0.116	1.622	5.794	2.086	0.463	0.232	0.232	0.232	0.232	0.116	0.116
6.00- 8.99	0.232	0.348	2.665	3.940	4.287	1.043	0.453	0.116	0.116	0.232	0.116	0.116
9.00-11.99	0.116	0.116	0.348	2.665	0.579	0.695	0.348	0.348	0.463	0.579	0.348	0.348
12.00-14.99	0.0	0.0	0.0	1.275	0.927	0.116	0.232	0.232	0.232	0.232	0.463	0.695
15.00-17.99	0.116	0.116	0.579	0.811	2.433	0.232	0.463	0.348	0.232	0.0	0.116	0.116
18.00-20.99	0.0	0.0	0.0	0.0	1.159	0.232	0.811	0.0	0.0	0.0	0.0	0.0
21.00-23.99	0.0	0.0	0.0	0.0	0.116	0.463	0.232	0.0	0.0	0.0	0.0	0.0
24.00-26.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27.00-29.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30.00-32.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33.00-35.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36.00-38.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39.00-41.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42.00-44.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45.00-47.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
48.00-50.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
51.00-53.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54.00-56.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COLUMN SUMS	0.811	0.927	5.910	14.948	12.167	3.708	3.360	1.970	1.854	1.622	1.854	2.086

Figure 17

DIRECTION(IN OEGREES)

SPEEO(CM/SEC)	172.5- 187.49	187.50- 202.49	202.50- 217.49	217.50- 232.49	232.50- 247.49	247.50- 262.49	262.50- 277.49	277.50- 292.49	292.50- 307.49	307.50- 322.49	322.50- 337.49	337.50- 352.49	ROW SUMS
0.00- 0.30	0.0	0.0	0.0	0.0	C.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.31- 2.99	0.927	1.854	0.695	0.927	0.232	0.116	0.232	0.232	0.232	0.348	0.232	0.232	12.399
3.00- 5.99	0.116	1.506	2.086	2.202	4.403	3.013	1.043	0.232	0.116	0.348	0.232	0.463	27.231
6.00- 8.99	0.116	0.116	0.927	3.360	2.202	0.463	1.275	0.463	0.232	0.232	0.116	0.116	23.291
9.00-11.99	0.348	0.232	1.506	3.476	2.433	1.390	0.0	0.0	0.0	0.0	0.116	0.232	16.686
12.00-14.99	0.579	0.811	0.348	0.348	0.116	0.463	0.0	0.116	0.0	0.116	0.0	0.0	7.300
15.00-17.99	0.463	1.159	0.232	0.232	0.463	0.348	0.116	0.0	0.0	0.0	0.116	0.116	8.806
18.00-20.99	0.0	0.0	0.0	0.0	0.0	0.695	0.0	0.0	0.0	0.0	0.0	0.0	2.897
21.00-23.99	0.0	0.0	0.0	0.0	0.0	0.579	0.0	0.0	0.0	0.0	0.0	0.0	1.390
24.00-26.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27.00-29.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30.00-32.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33.00-35.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36.00-38.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39.00-41.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42.00-44.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45.00-47.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
48.00-50.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
51.00-53.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54.00-56.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COLUMN SUMS	2.549	5.678	5.794	10.545	9.849	7.068	2.665	1.043	0.579	1.043	0.811	1.159	100.000

CURRENT IS RESOLVED AS A VECTOR FOR TOTAL PERIOO OF RECORO

AVERAGE SPEED IS THE SCALAR AVERAGE OF CURRENT FOR PERIOO OF RECORO

RESULTANT W-E IS -0.863 CM/SEC. RESULTANT N-S IS 0.393 CM/SEC. RESULTANT IS 0.948 CM/SEC. ANGLE IS 114.501 OEGREES

WEST AND SOUTH ARE POSITIVE

AVERAGE SPEED 8.25 CM/SEC. PERSISTANCE IS 0.11 TOTAL NO. READINGS 863.0 MAXIMUM SPEEO 22.470 CM./SEC.

READINGS TAKEN EVERY 10.0

FREQUENCY ANALYSIS FOR CURRENT METER DATA

STATION E

DIRECTION(IN DEGREES)

SPEED(CM/SEC)	352.5- 7.49	7.50- 22.49	22.50- 37.49	37.50- 52.49	52.50- 67.49	67.50- 82.49	82.50- 97.49	97.50- 112.49	112.50- 127.49	127.50- 142.49	142.50- 157.49	157.50- 172.49
0.00- 0.30	0.117	0.117	0.585	0.585	0.234	0.585	0.351	0.234	0.117	0.351	0.351	0.351
0.31- 2.99	1.170	1.287	2.456	1.170	3.275	1.988	2.573	1.170	1.170	0.702	0.468	0.702
3.00- 5.99	0.351	0.585	0.936	0.936	1.520	1.053	1.404	1.404	1.637	0.702	0.702	1.287
6.00- 8.99	0.351	0.468	0.0	0.0	0.585	3.158	0.234	0.0	0.117	0.234	0.0	0.0
9.00-11.99	0.468	0.234	0.702	1.404	0.936	1.404	0.117	0.234	0.234	0.936	0.234	0.234
12.00-14.99	0.0	0.0	0.351	0.936	0.702	0.351	1.404	0.585	0.819	0.117	0.0	0.0
15.00-17.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.117	0.117
18.00-20.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.00-23.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24.00-26.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27.00-29.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30.00-32.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33.00-35.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36.00-38.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39.00-41.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42.00-44.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45.00-47.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
48.00-50.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
51.00-53.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54.00-56.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COLUMN SUMS	2.456	2.690	5.029	5.029	7.251	8.538	6.082	3.626	4.094	3.041	1.871	2.690

DIRECTION(IN DEGREES)

SPEED(CM/SEC)	172.5-187.49	187.50-202.49	202.50-217.49	217.50-232.49	232.50-247.49	247.50-262.49	262.50-277.49	277.50-292.49	292.50-307.49	307.50-322.49	322.50-337.49	337.50-352.49	ROW SUMS
0.00- 0.30	0.117	0.117	0.351	C.468	0.117	0.234	0.936	0.585	1.053	1.287	0.234	0.117	9.591
0.31- 2.99	0.702	0.585	0.585	0.351	0.702	0.351	0.936	2.690	2.339	0.819	0.585	0.702	29.474
3.00- 5.99	1.637	2.339	0.819	0.351	0.585	0.585	0.585	2.456	1.170	1.871	0.351	0.351	25.614
6.00- 8.99	0.0	0.0	0.234	0.351	0.585	0.585	1.170	0.936	2.105	1.520	0.351	0.234	13.216
9.00-11.99	0.117	0.351	0.351	0.234	0.819	0.468	0.117	0.702	0.819	1.637	0.117	0.117	12.982
12.00-14.99	0.117	0.585	0.351	0.234	0.0	0.0	0.0	0.0	0.0	0.117	0.468	0.585	7.719
15.00-17.99	0.0	0.117	0.234	0.117	0.351	0.351	0.0	0.0	0.0	0.0	0.0	0.0	1.404
18.00-20.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.00-23.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24.00-26.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27.00-29.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30.00-32.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33.00-35.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36.00-38.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39.00-41.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42.00-44.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45.00-47.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
48.00-50.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
51.00-53.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54.00-56.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COLUMN SUMS	2.690	4.094	2.924	2.105	3.158	2.573	3.743	7.368	7.485	7.251	2.105	2.105	100.000

CURRENT IS RESOLVED AS A VECTOR FOR TOTAL PERIOD OF RECORD

AVERAGE SPEED IS THE SCALAR AVERAGE OF CURRENT FOR PERIOD OF RECORD

RESULTANT W-E IS -0.354 CM/SEC. RESULTANT N-S IS -0.475 CM/SEC. RESULTANT IS 0.593 CM/SEC. ANGLE IS 36.730 DEGREES

WEST AND SOUTH ARE POSITIVE

AVERAGE SPEED 5.14 CM/SEC. PERSISTANCE IS 0.12 TOTAL NO. READINGS 855.0 MAXIMUM SPEED 15.870 CM./SEC.

READINGS TAKEN EVERY 10.0

between the two stations. Computed also is the energy spectrum, the coherence and the angles of lead and lag.

The next major analytical step is the computation of dispersion coefficients using a first-order Markov chain model. The basis of this model is the following of a particle movement, and it does so by computing the probabilities of transitions between 80 possible states. Thus, the probability of a particular particle path is determined and can be utilized in predicting the dispersion characteristics from the current meter data obtained in the field. The computer program prints out a Transition Probability Matrix on 80 separate pages for each station, an example of which is shown in Figure 18. Across the top of the page are the direction categories of which there are eight in this case, and there are similarly eight horizontal rows corresponding to these same direction categories. Each such table corresponds also to a speed transition. Here, it is from 9-12 to 6-9 cm/seconds. The 64 probability values are printed within the matrix. Using this probability matrix information, the computer program can determine the most probable paths and the characteristics of the motion in the north-south and east-west direction. These characteristics include the standard deviation, the average distance, and the weighted standard deviation. Diffusion depends upon the magnitude and the variability of the current. This information, therefore, can be used to compute the dilution characteristics in the directions of interest. For example, using Equation 1, page 690, of the "Lake Hourly Dispersion Estimates" paper

$$(y^2) = 2\,Et$$

where: (y^2) is the variance of particle separation in cm^2
E is the diffusion coefficient in cm^2/sec
t time in seconds

the dilution, which would occur due to the water movement characteristics at Station E, off the Orient Heights Beach, in the westward direction is one quarter of the dilution which would occur in the eastward direction. In the northerly

9.0- 12.0

TO

6.0- 9.0

-22.5- 22.5	22.5- 67.5	67.5-112.5	112.5-157.5	157.5-202.5	202.5-247.5	247.5-292.5	292.5-337.5
0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)
0.03226 (60.0)	0.12903 (64.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)
0.0 (30.0)	0.0 (30.0)	0.09091 (62.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)
0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)
0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.12500 (63.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)
0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.04688 (61.0)	0.0 (30.0)	0.0 (30.0)
0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)
0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)	0.0 (30.0)

131134

Figure 18 - Transition Probability Matrix

IBM Canada Ltd.

9.0- 12.0

TO

direction, it is one-half of that in the easterly direction. Similarly, that in the south was one quarter that of the east. These figures are obtained by using Equation 1, above. The corresponding diffusion coefficients are given in the following table.

Diffusion Coefficients in Centimeters^2 Per Second	Direction
3.8×10^3	North
6.9×10^2	South
1.1×10^4	East (away from beach)
7.2×10^2	West (towards beach)

Using this same information and Equation 5, from the "Lake Hourly Dispersion Estimates" paper,

$$(C_{max}(X) = \frac{Q}{(2\pi)^{1/2} \; (y^2)^{1/2} \; (U)}$$

where: $(C_{max}(X))$ is the maximum mass in mg/cm^2
Q is the mass discharge in mg/sec
(y^2) is the weighted mean spread in cm^2
(U) is the weighted mean velocity in cm/sec.

the concentrations of a pollutant may be compared for these same directions. Where K is proportional to the mass discharge in milligrams per second of the pollutant, the predicted maximum concentration in the several directions in milligrams per square centimeter is given by the following table:

Predictions from Station E, Off of Orient Heights Beach

Current Meter Data

Maximum Concentrations	Direction
$K/19.6 \times 10^3$ cm^2/sec	North
$K/7.81 \times 10^3$ cm^2/sec	South
$K/52.9 \times 10^3$ cm^2/sec	East
$K/8.5 \times 10^3$ cm^2/sec	West

These same computations were made using the Markov chain transition probability matrices computed for Station A. However, for the directions out northeast and in southwest, these are as follows:

Predictions from Station A

Current Meter Data

Maximum Concentrations	Direction
$K/2.7 \times 10^4\ cm^2/sec$	Northeast (out)
$K/2.2 \times 10^4\ cm^2/sec$	Southwest

Using the transition probability matrix, the next step in the analysis builds up successive transition probability matrices for 40 time periods. The time periods chosen were 10-minute increments, and here again the speed classes were from 0 to 3 centimeters per second, 3 to 6 centimeters per second, 6 to 9 centimeters per second, etc. Each such set of transition probability matrices must be built up on the assumption of an initial state vector. Initial states of interest were chosen. Thus, for Station A, an initial state was assumed to be in the northeasterly direction of 7 1/2 centimeters per second. This was not entirely an arbitrary assumption, but one based upon previous information in the analysis. For Station E, two initial state vectors were assumed, one in the easterly direction at 4.5 centimeters per second and one in the northwesterly direction at 4.5 centimeters per second. From each probability matrix is computed the minimum weighted mean distances in each of the directions - north, northeast, east, southeast, south, soutwest, west, and northwest - the maximum weighted mean distances and average weighted mean distances, together with the probabilities associated with each of these values. Using this information, it is possible to plot envelopes of the probability of particle travel for whatever time increment is of interest. For example, after one 10-minute interval, two 10-minute intervals, three, four, five, up to 40 10-minute intervals. These plume-like plots are not plumes, however, but are

indicative of dispersion. Experimental verification for this approach has been published in the 1971 paper, "Lake Hourly Dispersion Estimates," referenced above. These plots are included as Figures 19, 20, and 21. Note that the minimum weighted mean distances have been used since these represent the worst-case conditions.

To interpret these plots, assume a particle is released at the current meter station and observed to move in the initial state fashion. Then at successive time increments the probability is that the particle will be found within the areas shown.

To further aid in interpreting the plots, giving the probable envelopes of particle travel predicted from the current meter data from Stations A and E, plotted in Figures 19, 20, and 21, the following probabilities have been computed from the results. These probabilities, it should be noted, apply to the entire period over which the current meter data was taken, or approximately one week, and are to be interpreted as the probabilities (or percentages of time) a particle is introduced into the water mass at either one of the two stations, and the initial state vector, as indicated above (and on the individual plots) will be found after the specified time within the plotted envelope. These probabilities, or percentages of time, are given in the following table:

The Probability, or the Percentage of the Period of Record, a Particle Will Be Found Within the Envelope, Plotted in Figures 19, 20, and 21

Station	Initial State Vector Average	After One Hour	After Two Hours	After Four Hours	After Six Hours
E	Northwest @ 4.5 cm/sec	14%	23%	33%	40%
E	East @ 4.5 cm/sec	25%	36%	44%	45%
A	Northeast @ 7.5 cm/sec	5%	12%	19%	20%

Here again, the back-and-forth flushing of the tide probably accounts for the high probability of pollutant persistence in this water mass, assuming, as these computations do, the worst case or low ranges of velocities.

Figure 19 depicts the poor pollution dispersion characteristics plotted for an initial state vector of 4.5 cm/sec in the northwesterly direction off of the Orient Heights Beach. With Figure 19 as a probable baseline envelope of dispersion, it is evident that the effect of the proposed fill (reducing exchange volume by 37%: See Mass Balance calculations) will further reduce this dispersion envelope by approximately 18% since velocity is reduced by one-half of the amount of volume reduction and tends to concentrate pollutants in the area. It is further evident that a southwesterly wind operating in this area will tend to blow this concentration on to the Orient Heights Beach.

Figure 20 depicts the probable envelope of particle travel from the current station off of Orient Heights Beach, assuming an initial state vector of 4.5 cm/sec in the easterly direction. Although not the most likely case for dispersion conditions in this area, it was felt that some analysis of best-case conditions be made. With the initial state vector moving away from the Orient Heights Beach, the dispersion improves as compared with Figure 19. However, the reduction of dispersion by 18%, due to the effect of the fill, tends to concentrate the pattern by reducing maximum excursion of the dispersion envelope in the easterly direction from 115 meters to 95 meters.

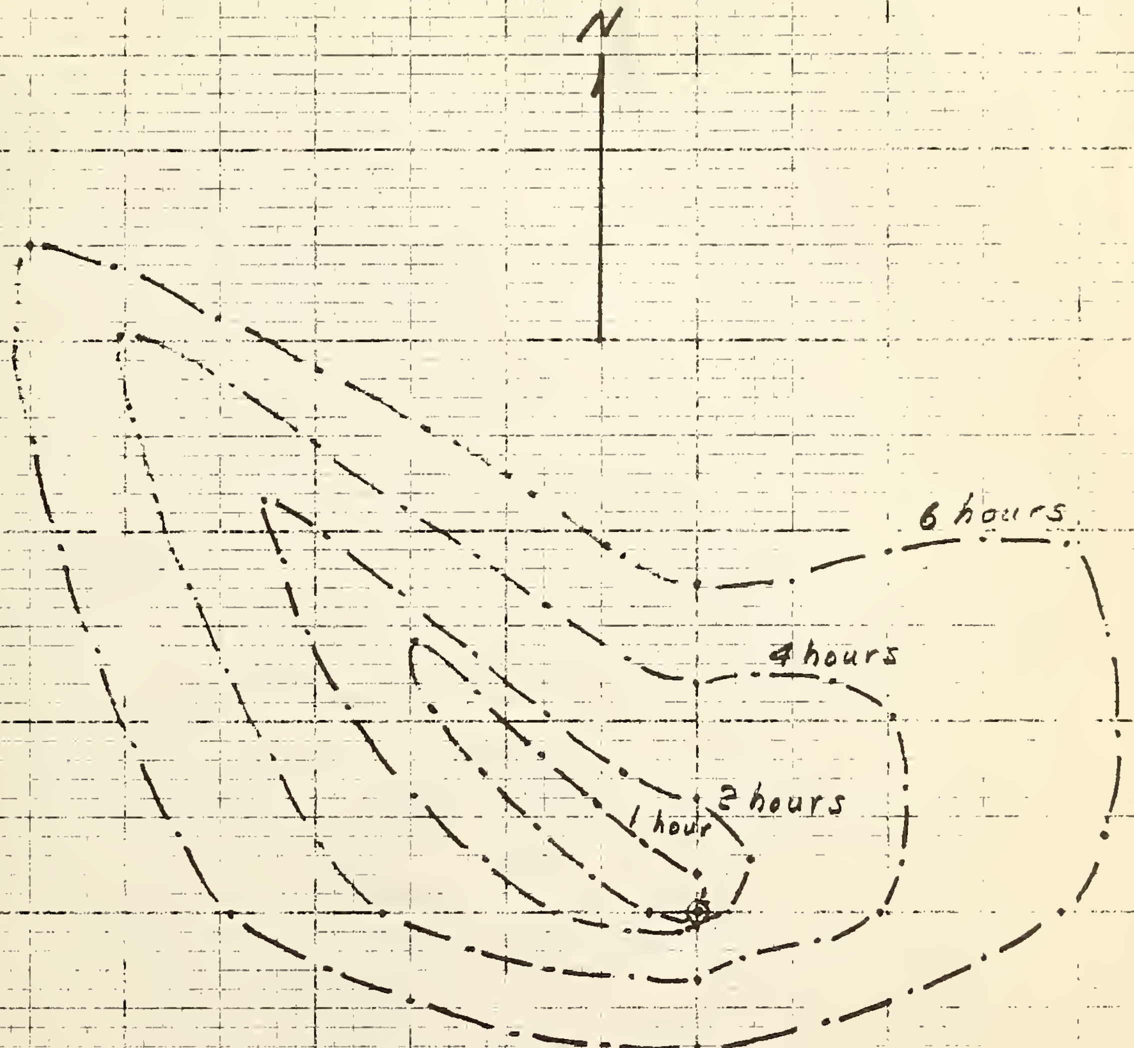
Figure 21 depicts the probable envelope of particle travel from the entrance to the Western Tributary Tidal Basin. This is not a particularly large envelope even considering that the initial state vector is 7.5 cm/sec, almost twice that evident for the current off of Orient Heights Beach. Here again, it should be noted that the effect of the proposed fill will be 18%, greatly reducing the size of this envelope.

The models utilized, coupled with the mass balance data, indicate that:

1. The baseline dispersion off of Orient Heights Beach is very poor.

2. The reduction in flow due to the proposed fill will tend to decrease this dispersion and concentrate whatever pollutants are off of the beach.

The attached folder contains transparencies of Figures 19, 20, and 21, which are the dispersion patterns before the proposed fill. In addition, Figures 19A, 20A, and 21A are included as transparencies. These represent the dispersion patterns showing the results after the proposed fill. They may be used as direct overlap for purposes of comparison.



Probable Envelopes of particle travel from current meter data for Station E Initial State Vector 4.5 cm/sec NW.

Figure 19

Scale 1/2" = 10 m

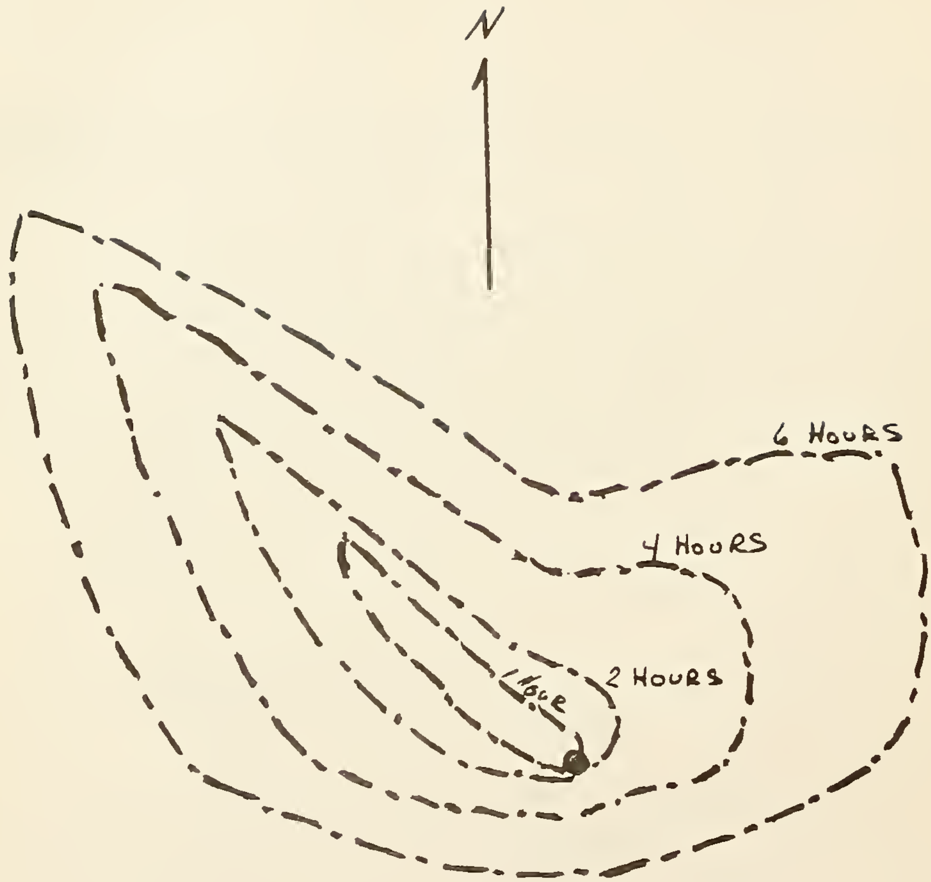
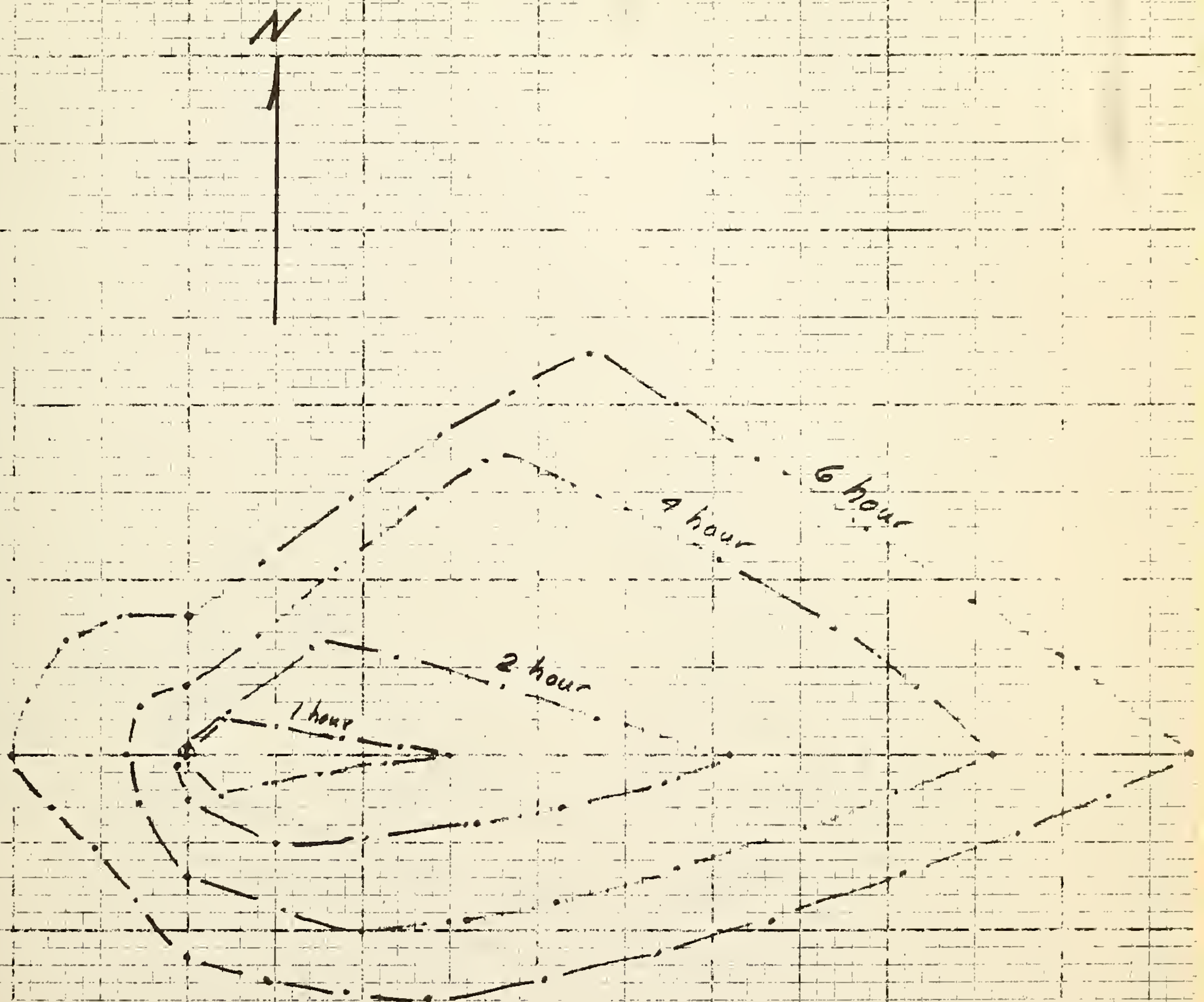


Figure 19A

Probable Envelopes of particle travel from current meter data for Station E
Initial State Vector 4.5 CM/SEC NW
WITH 18% effect of Proposed fill
Scale 1/2" = 10 M



Probable Envelopes of particle travel from current meter data for Station E Initial State Vector 4.5 cm/sec East.

Figure 20

Scale: 1/2" = 10m

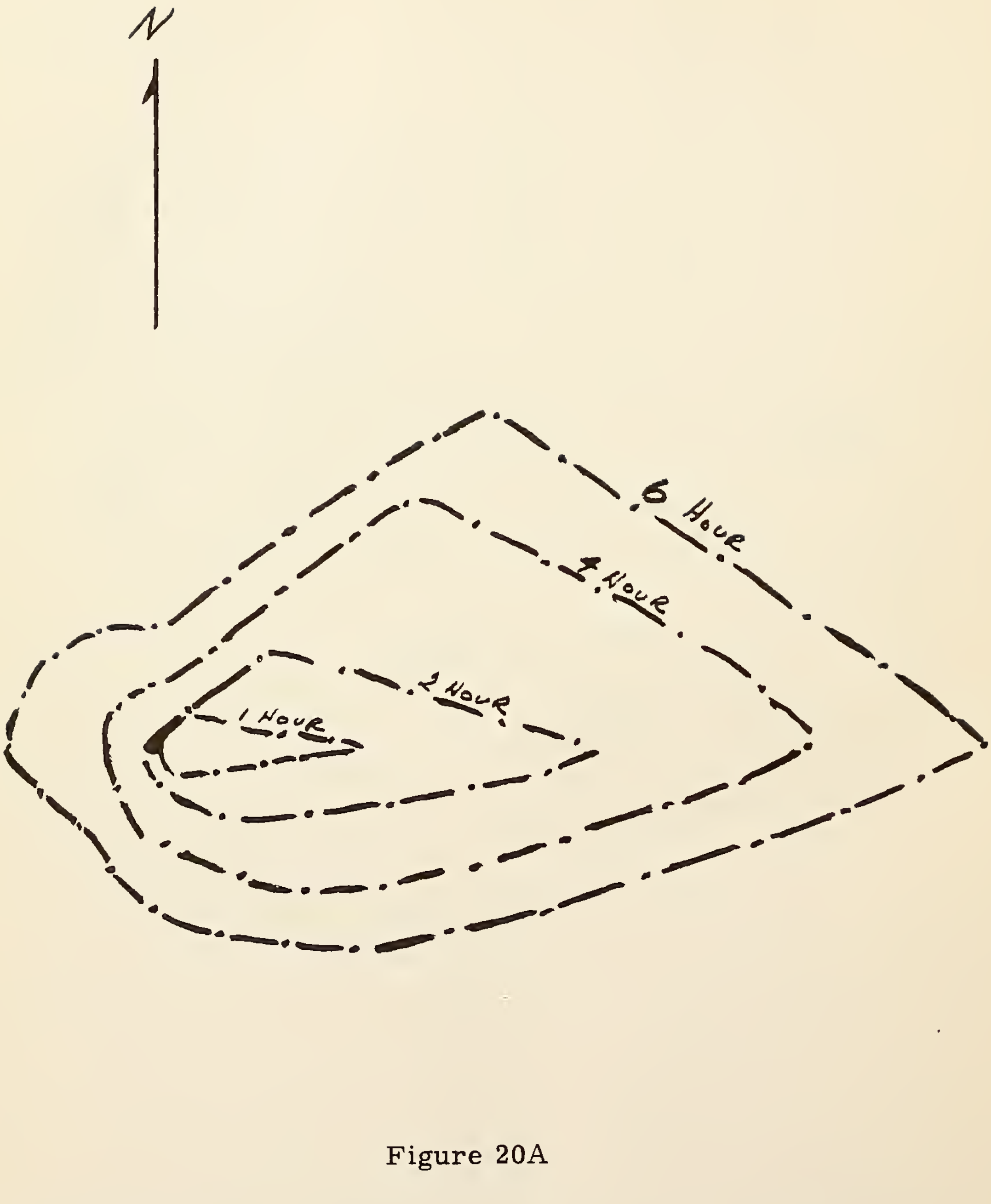
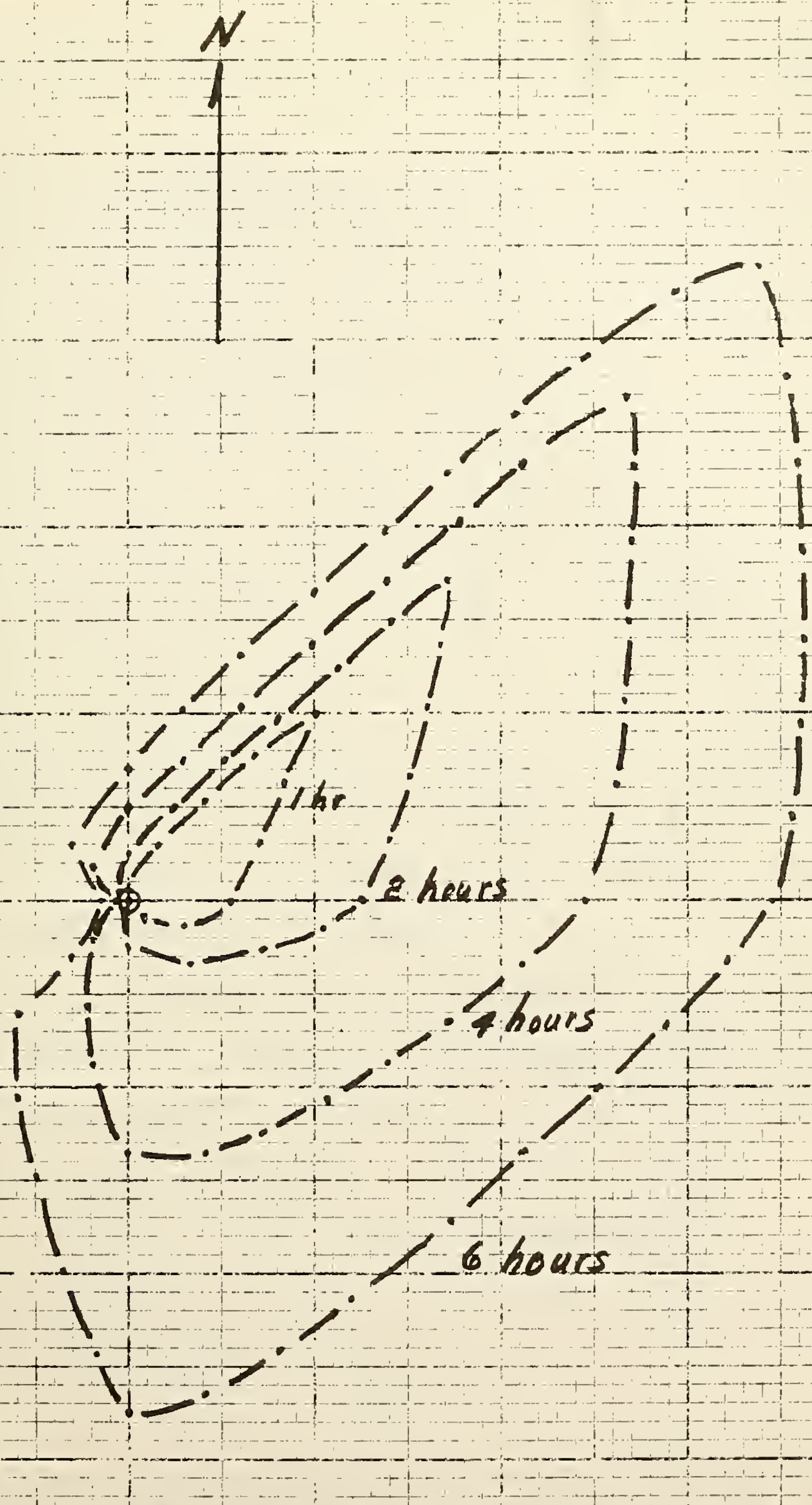


Figure 20A

Probable Envelopes of particle travel from current meter data for Station E
Initial State Vector 4.5 cm/sec East
with 18% Effect of Proposed fill
Scale: 1/2" = 10 M



Probable Envelopes of particle travel from
Current meter data for Station A
Initial State Vector 7.5 cm/sec NE.

Figure 21

Scale 1/2" = 10m

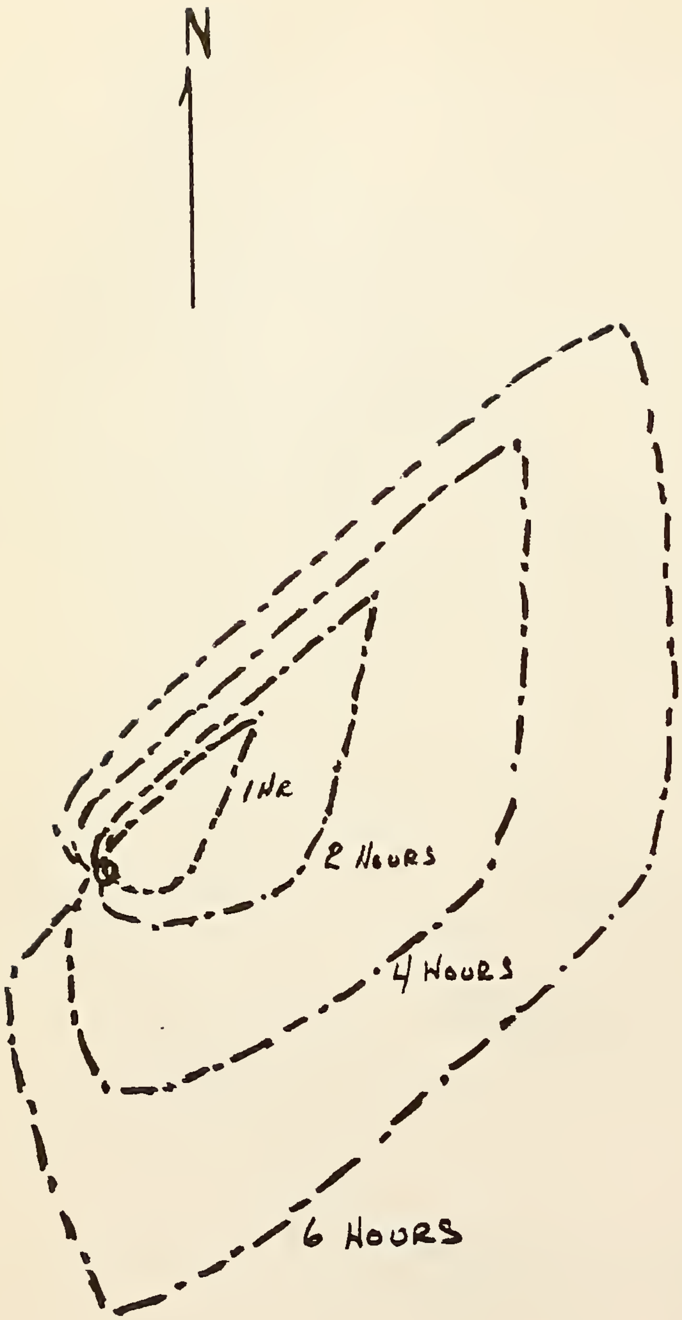


Figure 21A

Probable Envelopes of particle travel from Current meter data for Station A Initial State Vector 7.5 cm/sec NE with 18% Effect of Proposed fill
Scale 1/2" = 10 M

SECTION 5.0 RECOMMENDATIONS AND CONCLUSIONS

It should be recognized that a five-day survey of a body of water is a limited period of data acquisition upon which to base sound engineering judgments. However, the data gathered does agree with a priori conclusions.

The movement of the bodies of water, designated the Main Tidal Basin and the Western Tributary Tidal Basin, is almost solely induced by tidal action. Some effects due to winds are indicated by the data.

The sewer at the foot of Moore Street depends in general on tidal action to disperse and diffuse its effluent. Dispersion and diffusion would be greatly enhanced by the winds in the area, especially winds out of the northwest and southeast.

The proposed land fill will reduce the volume of water available for diffusion and dispersion in the Western Tributary Tidal Basin by almost 37%. It will also reduce the mixing effect of the northwesterly-southeasterly winds by reducing the fetch in these directions.

The dispersion off of Orient Heights Beach is limited at the present time, as is shown in Figures 19, 20 and 21. The application to the predictive model of a reduction in volume due to the proposed fill will further reduce that dispersion by approximately 18%.

The following conclusions can be drawn from this study:

1. Even without the proposed fill, the combined sewer outfall at the end of Moore Street presents an undesirable condition for the Orient Heights Beach.

2. The outfall of the sanitary sewer should be closed, or failing that extended to a location where the volume of tidal flushing is much greater than the present situation.

3. Less desirable would be a dredging program which after proposed fill would maintain the total volume of water within the Tributary Tidal Basin constant.

APPENDIX I

DATA PROCESSING

Data recorded by the unattended instruments used in this survey was processed to make the information available for detailed analysis as discussed in the main volume of the report. In the case of analog strip chart tide gauge records, this processing was a straightforward manual chart reading procedure. For the digital film current meter records, the procedure is much more involved and is discussed below.

The Geodyne Model 102 Current Meter is capable of recordings from 150 to 200 thousand digital current vector measurements on a 100 ft. reel of 16 mm film. While this film record may be scanned visually, it is an impossible task to process the data manually. A specially built computer film reader is maintained by the Environmental Equipment Division of EG&G for the purpose of transferring every bit of the recorded data from the 16 mm film to IBM compatible computer tape. The details of this facility have been discussed in a paper presented at the 1st U. S. Navy Symposium on Military Oceanography in June 1964 entitled "Automatic Reading and Processing of Current Speed and Direction, Precision Temperature Records, and Wave Data from Unattended Instruments". This paper has been published and a Xerox copy is enclosed herewith.

The rational for this type of current measurement and recording has also been discussed in a paper in 1968 presented at the Marine Technology Society's Instrumentation Committee Symposium on Current Instruments and Techniques. It is entitled "An Evaluation of the Richardson Current Meter System" and a copy of this is also appended hereto. In brief, it can be summarized by noting that a valid determination of water current movement can only be had by obtaining a large number of

closely spaced measurements of this vector quantity which are then combined to form meaningfully accurate vector averages. Instrument systems which attempt to reduce the data processing problem by taking fewer measurements tend,in one way or another, to distort the data. In this connection, it is important to note that the above mentioned computer reader is designed solely to perform a transfer of the data from the original digital film record to the IBM tape with the raw data now on the IBM tape. It is then possible to perform valid data reductions such as the computation of vector averages used here without fear of distorting the data inadvertently.

The Model 102 Current Meters used in the present survey were set to record in what is known as the continuous mode; that is to say, samples of data were recorded every five seconds continuously for the entire period of the survey. These are then combined as 10 minute vector averages using the IBM tape obtained from the reader thereby generating a second IBM tape or decoded tape as it is called. A choice of 10 minute averages was selected to facilitate the application of the mathematical modeling discussed in the main body of the report under Data Analysis.

In the contemporary world of automatic data processing, one of the main barriers to wide spread use of the capabilities of modern digital computers is the transfer of data from one computer installation to another. The problem is one of format compatibility and is one which the Environmental Equipment Division has confronted successfully. For example, many of the computer programs designed to handle data recorded by the Geodyne Current Meters are available and in operation at the Woods Hole Oceanographic Institution's Information Processing Center in Woods Hole, Massachusetts. These augment and complement the programs which the Environmental Equipment Division has in operation on computer facilities in the Boston area.

Furthermore, our consultant, M. D. Palmer, of the Ontario Water Resources Commission, has developed programs for predictive modeling, and these are operational on IBM 360 installations. In order to use these programs, however, the information must be in a format usable by the particular computer. Thus, using special tape translation programs, the above-mentioned decoded tape is transformed to a WHOI format and then to a 360 format. In each case, intercomparison checks were performed to validate the correct transfer of the data. Thus, a vector average listing from the WHOI format is compared and found to agree with the vector average listing from the 360 format. This type of procedure ensures accurate and valid quality control* on the processed data.

How each of the digital computer tapes are used in data analysis for interpretive purposes is discussed in the main body of the report. Computer outputs generated by the tape translation program are given as Figure 22.

*Another quality control procedure employed in this data reduction is the computation of the Normalized Unit Vector (NUV) as discussed on Page 234 of the paper on Automatic Reading and Processing. It provides an indication of the variability of the recordings indicating, thereby, if the data is too random to yield meaningful averages.

1509661

```
RUN  (LMN,TEMP)

******************
DATA/ E3G401402
******************

FILE CREATED/   15:12 APR 20,'71                                              SOURCE/   06

COMMENT/

LOCATION/   42 23.02 N     70 59.40 W                             MAGNETIC VARIATION/  15 W
DATA TIME ORIGIN/ 71- IV -09  18.30.00.000 Z
  SAMPLES TAKEN EVERY    600.000 SECONDS
*****************************************************************************************
**** DATA SEQUENCE **** UNITS ***** TYPE * MANF *** INST *** DEPTH M  ** BIAS VALUE ****
*****************************************************************************************
**(1) COMPASS      * 128.LVL.MIN  *  B   *  02  *          *    0.00 *              0
**(2) VANE         * 128.LVL.MIN  *  B   *  02  *          *    0.00 *              0
**(3) DIRECTION    * 128.LVL.BIN  *  B   *  02  *          *    0.00 *              0
**(4) SPEED        * MM/SEC       *  H   *  02  *          *    3.00 *              0
**(5) TIME         * MS           *  T   *  02  *          *    0.00 *              0
**(6) COMPASS NUV  * NON-DIM      *  R   *  02  *          *    0.00 *  0.00000
**(7) VANE NUV     * NON-DIM      *  R   *  02  *          *    0.00 *  0.00000
**(8) OIRECTION    * DEGREES      *  H   *  02  *          *    0.00 *              0
**(9) INCLINOMETER *  DEGREES     *  H   *  02  *          *    0.00 *              0
 ILLEGAL CHARACTER IN RECORD     122
 ILLEGAL CHARACTER IN RECORD     123
 ILLEGAL CHARACTER IN RECORD       0
 ILLEGAL CHARACTER IN RECORD       0
 ILLEGAL CHARACTER IN RECORD       0
 ILLEGAL CHARACTER IN RECORD       0
 EGGTRN ERROR CODE=1  (NO ASTERISK LINE)

 TOTAL NUMBER OF OUTPUT CYCLES *     900

*EXIT*
```

AUTOMATIC READING AND PROCESSING OF CURRENT SPEED AND DIRECTION, PRECISION TEMPERATURE RECORDS, AND WAVE DATA FROM UNATTENDED INSTRUMENTS

by

P. F. Smith, K. E. Perry, and A. L. M. Dingee, Jr.
Geodyne Corporation Waltham, Massachusetts

Photographic recording has been used for many years in oceanographic instruments for the obvious reason that it is a most efficient, reliable and uncomplicated technique. In fact, several of the earliest current meters used this recording method: The Mesureur de Courants de O. Pettersson described in 1913 (Ref. 1); the Appareil "Idvac" described in 1931 (Ref. 2); and the Winters Photographic Recording Current Meter described by Thorade in his Handbook of 1933 (Ref. 3). It is most probable that the photographic recording method was chosen not only for the technical advantages mentioned above, but also because it provided the oceanographer, probing the "unseen depths" a way of "seeing" what was going on. It was in effect an extension of man's senses into the ocean.

As a consequence all of these early instruments photographed what a man might like to have watched had he been able to be there. And this approach is still in use today. For example, the German Hydrographic Office has recently adapted a photographic recording bottom-mounted tide gauge for temperature recording by replacing the differential monometer with a thermometer. And there are many other examples both old and new of this type of photographic recording. This is not to imply that these methods are valueless, but only they are inherently limited and perilously inapplicable as we attempt to extend our observations in both space and time by the use of the modern buoyed instrument approach.

It was not until a digital film recording current meter was designed (Ref. 4) which after considerable development enabled man to relinquish his "you are there" approach to film recording oceanographic instruments. This step to high speed digital recording is exactly analogous to that made when mechanical computers ceased duplicating human decimal calculation methods and adopted the unhuman but far faster and more efficient binary arithmetic. The benefits and the problems that ensued are in like manner similarly analogous. The benefits, in this case for oceanographic research, are, simply stated, the creation of fast, accurate, and high capacity methods of data acquisition commensurate with the complexities of the ocean; and the resulting problem; how do you handle and process this new recording media? The solution is the subject of this

paper, for having been successfully applied to current meters, this technique has been extended to precision temperature recording, wave recording, wind recording, and numerous other parameters.

Just as a photograph of a dial or a pointer has the advantage of providing a visual record, a digital film record can be visually checked, but here the image is a pattern representing binary numbers (i. e., ones and zeros) or time pulses. Usually a binary one is a spot on the film and a zero the absence of a spot. Figure 1 is a section of a Current Meter Record. On this film, two seven-level binary numbers are recorded which have been generated by optical encoding discs (Ref. 4) driven respectively by the current sensing vane and a compass (Fig. 2). Recorded also are pulses generated by the rotor rotation. A ten level binary number generated by a transistorized automatic high-speed bridge balancing circuit (Fig. 3) is recorded on the film section shown in Figure 4. Here, eight separate numbers are recorded sequentially in 24 seconds, representing as many separate temperatures to better than one part in one thousand. Several groups of these recordings are shown.

In addition to optical disc encoding and electronic logic encoding, magnetic switch and diode matrix encoding have been employed. Figure 5 is a section of film obtained from a wave recorder using this technique (Ref. 5). In this case, an arbitrary binary table of numbers corresponds to wave height. Among the other parameters which have been recorded on digital film are instrument depth, mooring tension, as well as wind speed and direction. In fact, instruments now exist which will record sequentially up to any 64 resistances, voltages or currents (i. e., transducer outputs) to better than one part in four thousand (i. e., a 12 level binary number) in 8 seconds.

At the present state-of-the-art, 180,000 sets of recordings (in the case of the current meter having three values each) may be made on one reel of film. But why do oceanographers need this amount of data at this high rate except under most exceptional conditions when most often only variations having tidal periods or diurnal periods or seasonal periods are of interest? The answer to this is the answer to why digital film recording is justified (especially in moored instrument systems) and why, therefore, automatic reading and processing have been developed.

Oceanographic Instruments sample the value of time dependent variables. In fact, so do most recording and telemetering instruments. This is undoubtedly why Mallinckrodt and Stewart are so correct in saying that "the process of sampling continuous data is perhaps so familiar.....(to scientists)..... as to have led to a certain carelessness with respect to possible adverse effects of the sampling process itself on the accuracy of recoverable data." This statement is in their excellent paper on Aliasing

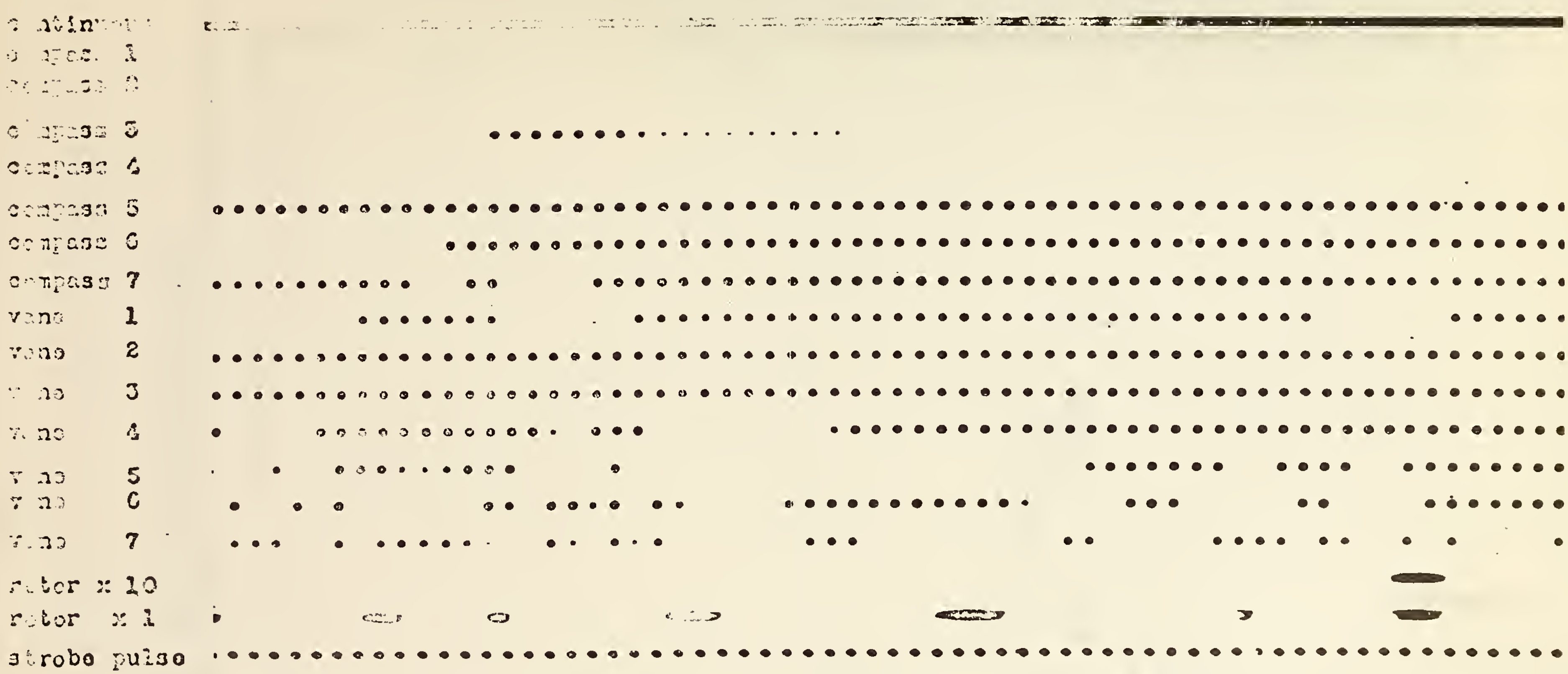
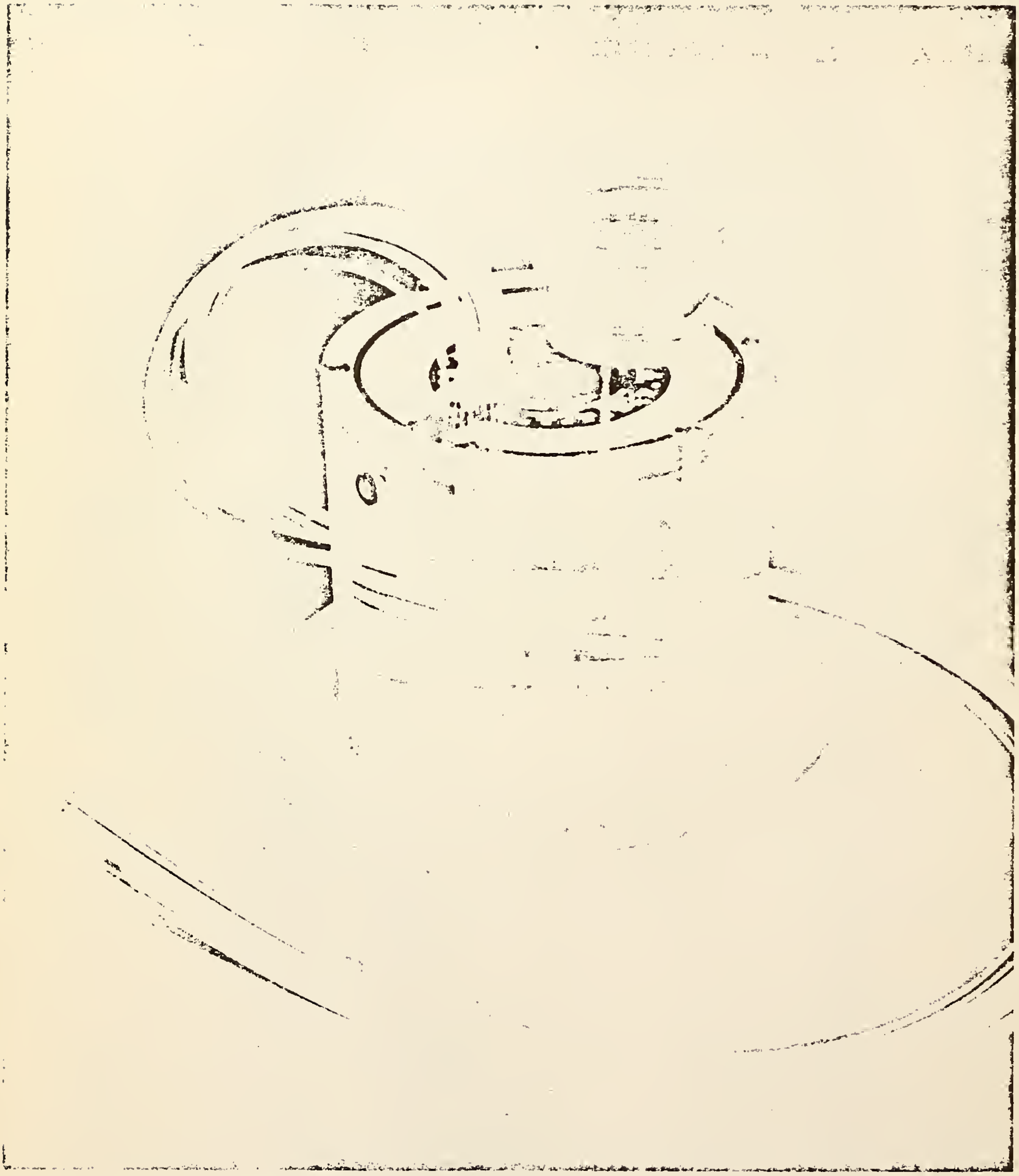


FIGURE 1 ENLARGED SECTION OF 16 MM DIGITAL FILM RECORD FROM RICHARDSON CURRENT METER WITH CHANNELS IDENTIFIED



GURE 2 DIGITAL COMPASS SHOWING OPTICAL ENCODING DISC AND FIBER OPTIC ARRAY FOR DISPLAYING DISC PATTERN IN CAMERA FIELD OF VIEW

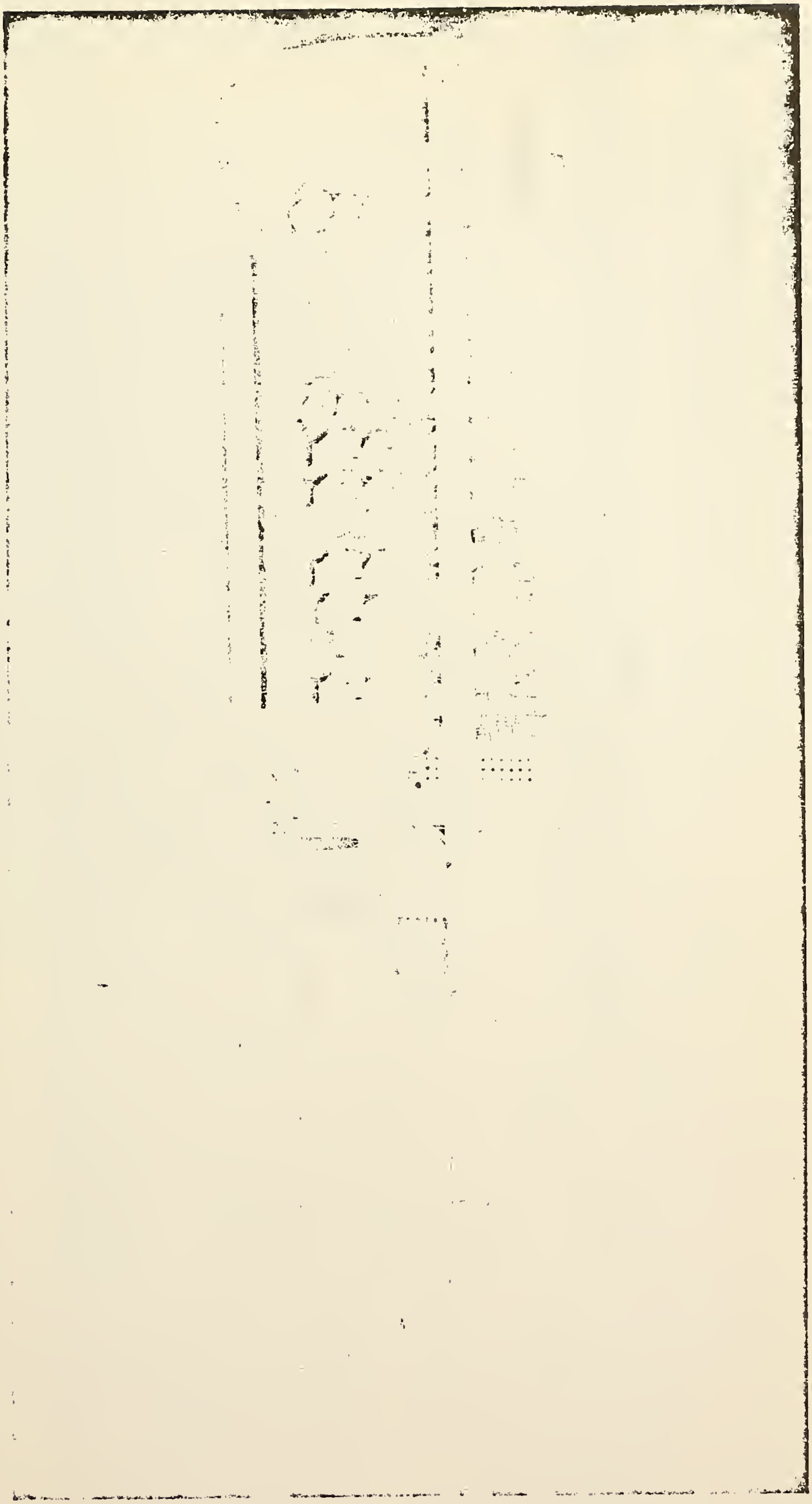


FIGURE 3 DETAIL OF DIGITAL TEMPERATURE RECORDER SHOWING LOGIC CIRCUITRY AND LAMP ARRAY AND RECORDING CAMERA

G

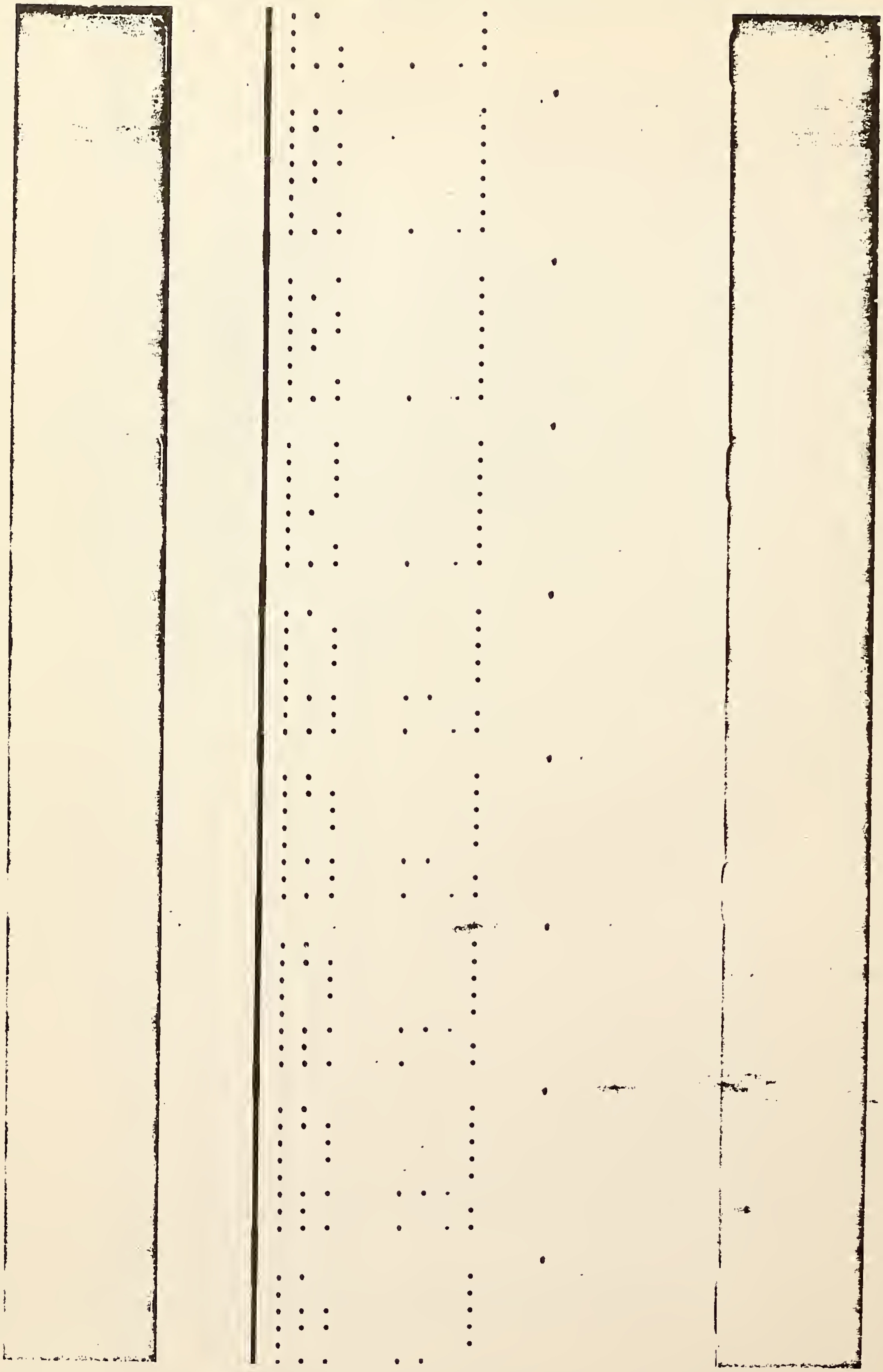


FIGURE 4 ENLARGED SECTION OF 16 MM DIGITAL TEMPERATURE RECORDER FILM

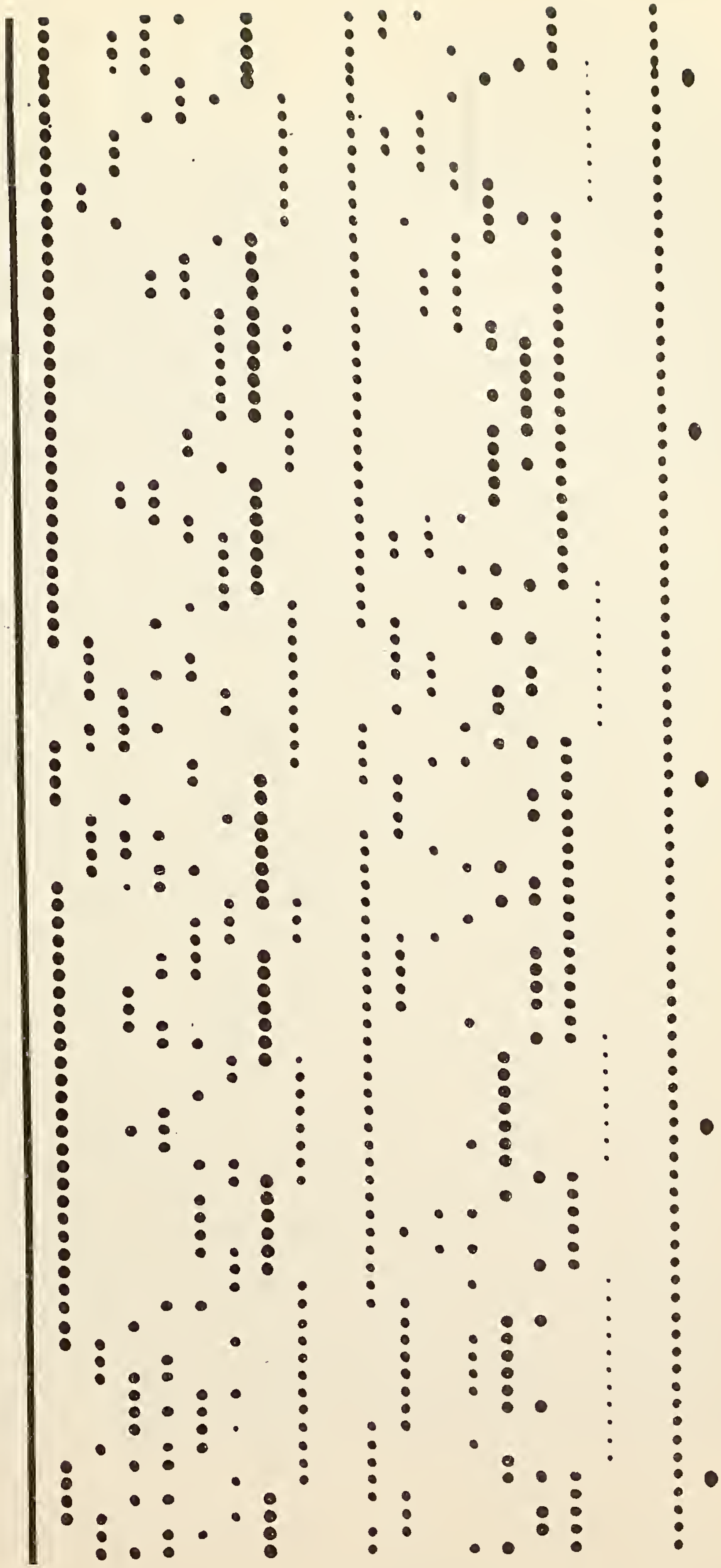


FIGURE 5 ENLARGED SECTION OF 16 MM DIGITAL WAVE RECORDING FILM

Errors in Sampled Data Systems, (Ref. 6) one of a number of fairly recent discussions (Refs. 7, 8) concerning the applicability of the sampling theorem to practical data collection problems. One of the most recent papers on this subject is aimed directly at sampling by buoyed oceanographic instruments (Ferris Webster, Ref. 11). The Sampling Theorem defines precisely the rate at which samples must be taken to recover perfectly a time dependent function. The rate is 2f samples per second where the function has no components higher than f cycles per second. While this appears simple enough, Gardenhire (Ref. 7) says this is "probably one of the most misunderstood and misquoted theories in use." The carelessness and misunderstandings are easily appreciated as one attempts to apply this theorem to real problems. First, one rarely knows the upper limit "f" in the spectrum of a signal being studied, or otherwise it would not be under investigation. Furthermore, no reliable filter, if one is employed, cuts off exactly at some single frequency. Secondly, and this is most subtle and most crucial, the all important distinction between the frequencies of interest in the signal and the frequencies present in the signal is often missed resulting in a modification of the theorem for "practical" purposes. Hence 2F samples are assumed to be all that are required where F is the highest frequency of interest (say a semidiurnal component) and then some multiple of 2F (perhaps 2, 3, 10 or 30) is actually recorded just to be well on the "safe" side.

In truth, the frequencies of interest are NOT relevant to the problem. When this modified and incorrect criterion is used "irrevocable, irreversible damage is done to the entire function" of interest (Ref. 6). This is graphically demonstrated by Figure 6 taken from Mallinckrodt and Stewart (Ref. 6) where two sinusoids are shown correctly and incorrectly sampled. Since all time dependent functions can be treated as the sum of sinusoids, the extension of this argument to complex waveforms is rigorous. The correct sample rate resolves all components present in the signal, i. e., to which the system responds. McRae (Ref. 8) gives a very illuminating set of tables of sample rates for sampling signals having various cutoff characteristics to obtain a required interpolation error. The theoretical rate of f/2 comes out for ideal signals with infinite cutoff after f. For more realistic signals having say a 6 db/octave rolloff above f, the number of samples required for a 10% interpolation error increases to 119! The mistaken description of the sampled function accounts for the term "aliasing" to describe the disastrous results of mis-sampling. In communication terms, sampling may be thought of and analyzed as the modulation of a signal by the sampling frequency. This effect is demonstrated in Figure 7, also taken from Mallinckrodt and Stewart. It can be shown that the signal spectrum may be thought of as folded back on itself at multiples of $f_s/2$, often called the Nyquist frequency, resulting in the aliasing of the high frequency data into the low frequency portion of the spectrum. After the samples have been taken, there is no way to distinguish the aliased information from valid low frequency data.

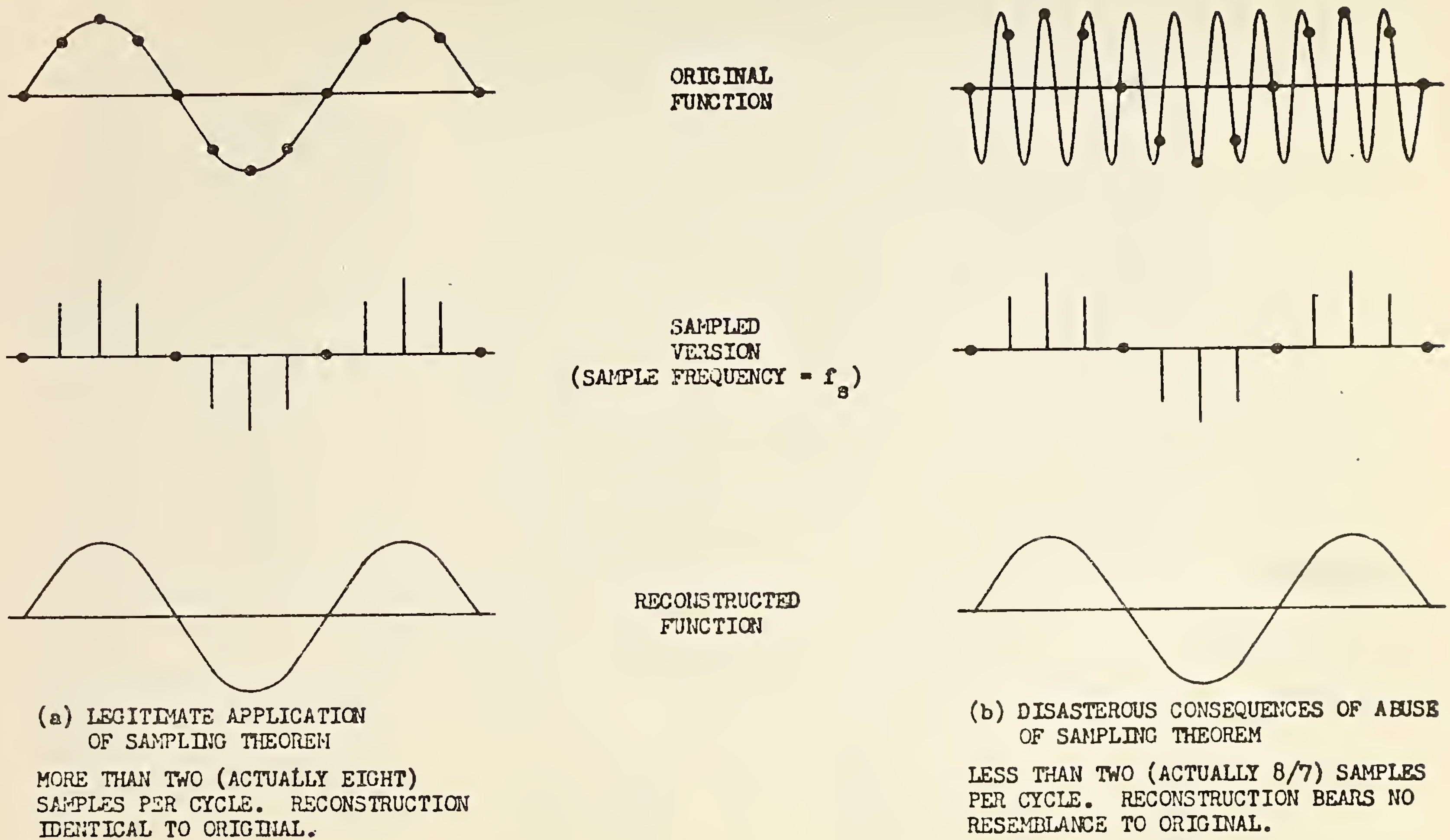


FIGURE 6 ILLUSTRATION OF PROPER AND IMPROPER SAMPLING OF SINGLE SINUSOIDS (FROM MALLINCKRODT AND STEWART, REFERENCE 6)

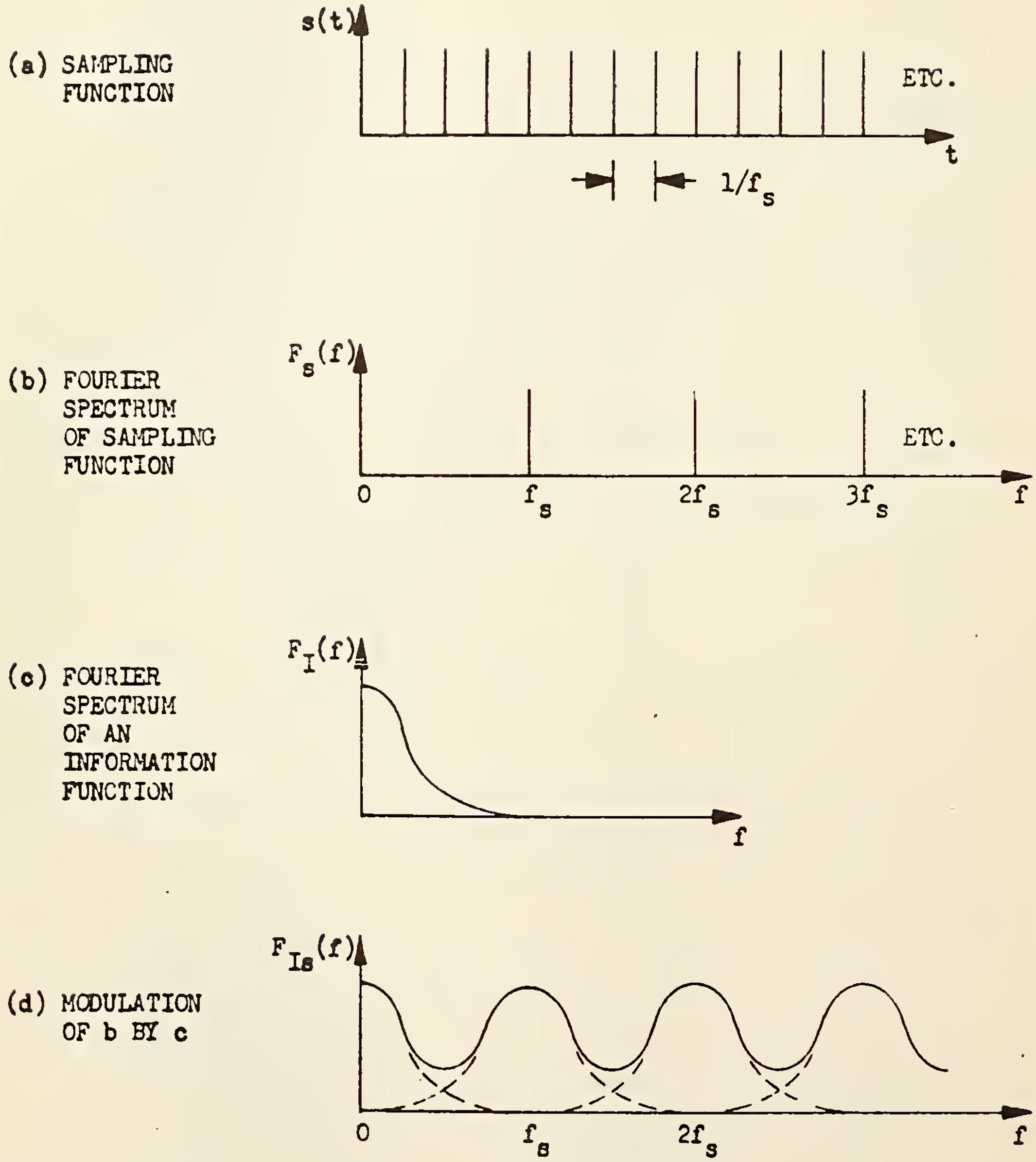


FIGURE 7 ILLUSTRATION OF THE MODULATION OF SIGNAL SPECTRUM OF A SAMPLING FUNCTION (FROM MALLINCKRODT AND STEWART REFERENCE 6)

In addition to the papers referenced above, a thorough discussion of this matter may be found in the MIT Technology Press Volume "Notes on Analog - Digital Conversion Techniques" edited by Alfred Susskind. (Ref. 9) The important fact to be remembered is, however, that the criteria for correct sampling is, as this text shows, "completely independent of the use which is to be made of the sample function."

Now the amount of work involved in data processing becomes impressive as soon as one takes enough data to circumvent the aliasing problems. For example, an experienced girl, using a specially adapted film viewer and an IBM Key Punch, can read 100 sets of data from a current meter film to IBM cards in one hour. One film, therefore, containing 180,000 sets of data, would require 225 eight-hour working days for reading in this manner. The Film Reader shown in Figure 8 reads a film in one hour, transferring every bit of data to IBM Format Binary Magnetic Tape simultaneously generating an analog strip chart monitor record of the data. The film reader is a variable program flying spot scanner having a resolution of one part in 600 across the film with an output channel capability of twenty-four. Provision is made to accommodate the full range of density and contrast encountered in recorded film including variations of these within any one film. The Video signal from the scan logic is displayed on a slave scope for the convenience of the operator. An example showing a section of a strip chart record from the Reader is shown in Figure 9. This is a current meter record taken off Edgertown, Martha's Vineyard, where the current flow is governed by the tidal wave proceeding up the Atlantic Coast and through Nantucket Sound. The sharp direction change with the tide is readily apparent, as is the fact that the speed is markedly different in the two directions. While these strip chart records provide the oceanographer with a quantitative overall look at his data, detail d analyses are performed on the binary magnetic tape with the aid of a computer. To illustrate the usefulness of this technique, a number of examples will be shown using current meter data, first to demonstrate the aliasing problem and then to demonstrate the applicability to oceanographic studies of this technique.

The effect of a sampling rate too low to resolve all frequency components in a signal is, in effect, to generate noise which is superimposed upon the signal. The computed data shown in Figures 10 and 11 taken from Webster's paper (Ref. 11) illustrates this point beautifully. Here the data was artificially aliased by having the computer sample the data at ten minute intervals. When ten minute averages are computed using all the samples recorded (1,200/10 minutes) the results are quiet and uncontaminated by the noise arising from the improper sampling. Another good example of this source of noise is to be found in the common practice of recording water temperatures with thermistors having time constants of the order of a few tenths of a second at sampling intervals of 5 seconds or greater. The rate is high enough to resolve

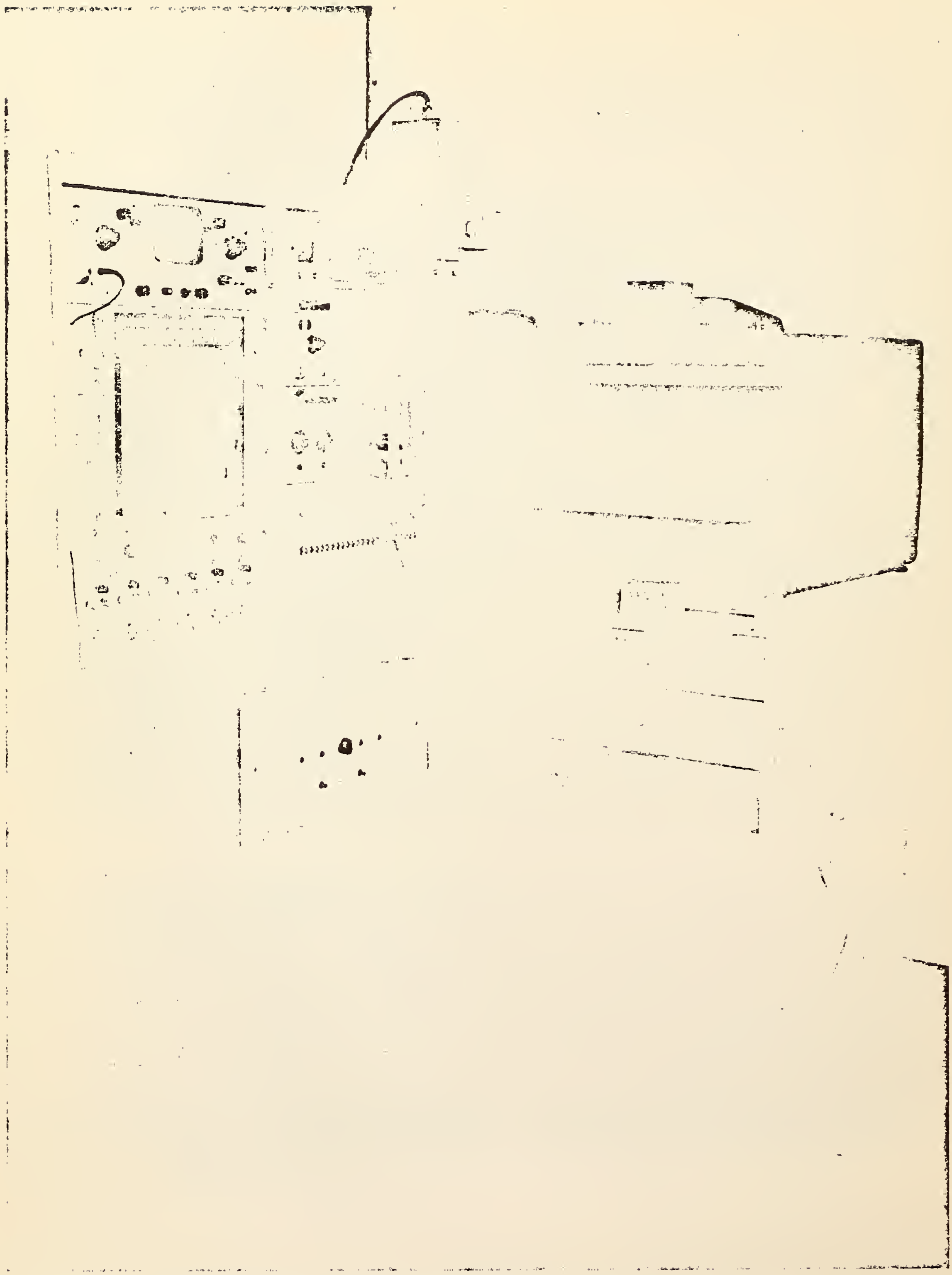


FIGURE 8 GEODYNE FILM READER SHOWING MAGNETIC TAPE AND STRIP CHART RECORDERS AND VIDEO MONITOR SCOPE

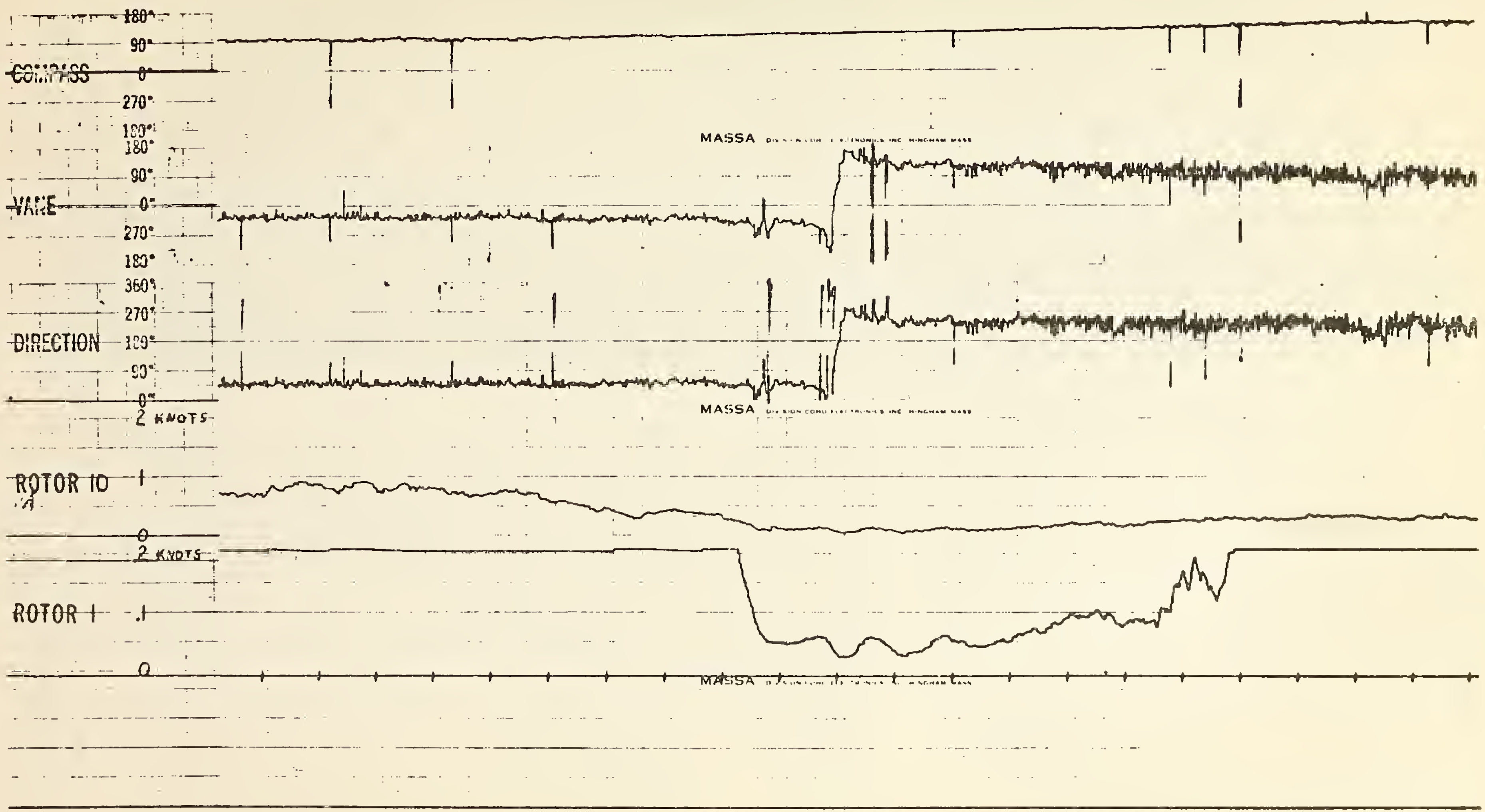


FIGURE 9 ANALOG STRIP CHART OUTPUT GENERATED DURING AUTOMATIC READING OF CURRENT METER DIGITAL FILM RECORD. NOTE ABRUPT CHANGE OF SPEED AND DIRECTION.

CURRENT METER LISTING AND PLOT. FILM NO. 101076

SLOW STROBE. 1200TERMS BETWEEN STROBES

SEQ	COM X	VAN •	VEL V
600	200	25	138
1800	186	25	89
3000	174	26	124
4200	174	28	126
5400	191	17	122
6600	208	11	89
7800	188	45	48
9000	295	323	25
10200	312	73	25
11400	326	68	25
12600	343	56	46
13800	0	53	49
15000	8	53	50
16200	31	53	49
17400	37	39	60
18600	45	34	58
19800	53	31	66
21000	56	31	68
22200	65	31	62
23400	56	51	61
24600	53	37	45
25800	70	31	56
27000	65	28	46
28200	76	23	55
29400	73	31	62
30600	65	39	47
31800	73	42	55
33000	17	113	46
34200	68	51	50
35400	8	127	42
36600	225	259	56
37800	236	242	55
39000	242	264	60
40200	256	318	25
41400	264	329	34
42600	264	318	51
43800	264	284	60
45000	264	343	54
46200	259	340	66
47400	248	278	51
48600	248	332	54
49800	250	326	63
51000	245	335	54
52200	248	318	61
53400	250	3	49
54600	256	326	63
55800	256	312	60
57000	259	6	54
58200	259	329	49
59400	262	343	58
60600	259	321	42
61800	264	343	57
63000	264	343	44
64200	264	326	49
65400	262	321	43
66600	264	343	46
67800	264	326	45
69000	264	315	50
70200	253	338	63
71400	250	323	70
72600	253	340	54
73800	239	8	61
75000	262	335	58
76200	259	326	52
77400	267	11	58
78600	259	354	54
79800	264	323	53
81000	259	318	57
82200	259	354	56
83400	236	332	56
84600	253	343	41
85800	253	335	50
87000	245	3	44
88200	245	8	41
89400	250	346	38
90600	256	11	47
91800	262	354	45
93000	264	0	38
94200	250	346	39
95400	259	11	25
96600	267	6	45
97800	267	20	40
99000	278	11	37
00200	284	8	-46
01400	290	6	52
02600	298	6	55
03800	309	357	54
05000	304	8	52
06200	309	6	55
07400	315	357	60
08600	312	8	51

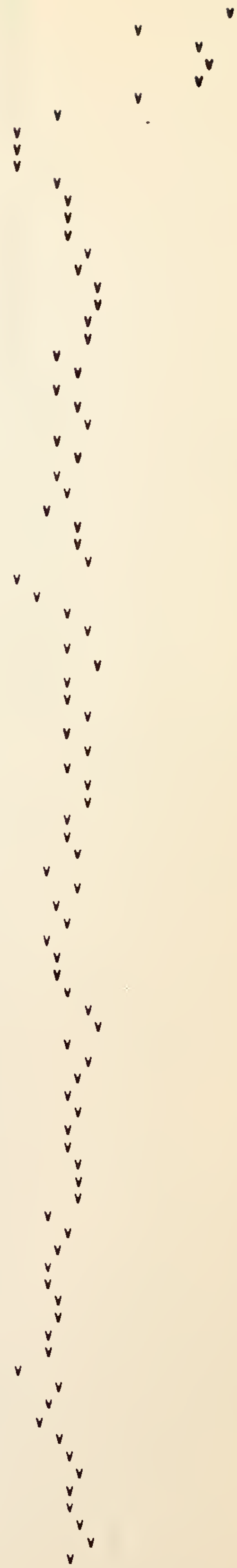


FIGURE 10 COMPUTER LISTING OF TEN MINUTE READINGS OF CURRENT METER COMPASS, VANE AND VELOCITY (MAGNITUDE), SHOWING SCATTER DUE TO ALIASING. (FROM WEBSTER REFERENCE 11).

Lake Hourly Dispersion Estimates from a Recording Current Meter

MERV D. PALMER AND J. BRYAN IZATT

Ontario Water Resources Commission, Toronto, Ontario, Canada

Mean hourly dispersion coefficients are predicted by using a first-order Markov chain model developed from continuous hourly current meter records at a fixed point. Dispersion coefficients compare favorably with other studies. The Eulerian data are assumed equivalent to Lagrangian because the Reynolds numbers were large, and because the velocity field was homogeneous over the distances considered. A conventional dye injection study at Port Maitland on Lake Erie verified the Eulerian to Lagrangian data conversion. Concentrations as a function of distance for a constant continuous point source of a passive contaminant are computed. A method for determining the maximum, mean, and minimum probable distances traveled by a particle in a period of hours is presented.

Recording current meters installed in the near-shore areas of the Great Lakes have revealed the variability of the water movements in both magnitude and direction with time and geographical location [*Hamblin and Rodgers*, 1967; *Noble*, 1961; *Palmer*, 1968]. A typical time history is presented in Figure 1. This variability is a major obstacle in the development of dispersion characteristics. Conventional Lagrangian methods using dye injection or drogue trackings would have to be repeated many times to obtain hourly estimates of dispersion. Use of these methods would be restricted to daylight hours. Another approach is to estimate local hourly dispersion characteristics from recording current meters under the assumption that the Eulerian measurements approximate the Lagrangian determinations for a period of hours in which the Reynolds number is very large and the velocity field is spatially homogeneous. This paper outlines a method for predicting hourly dispersion characteristics of a passive contaminant from recording current meter records. The method is based on the development of first-order Markov chain transition probability matrices from hourly current readings of a month's record. The hourly current readings are vector averages of 10-min readings. This development was applied to current meters operated on the northern shore of Lake Erie from August to November 1968 (see Figure 2). The assumption that the Eulerian measurements approximate Lagrangian determinations on a local hourly basis was verified with a Lagrangian experiment.

DEVELOPMENT OF METHOD

A first-order (hourly) transition probability matrix is obtained for 80 designated current states by examining monthly records of currents hour by hour [*Palmer*, 1970*a*]. Probabilities of any of the designated current states existing after n hours can be determined by operating on the first-order matrix [*Bharucha-Ried*, 1961]. For any time period, the probability of each of the possible hourly sequences of current states can be determined. The sum of the probabilities for all sequences must be the number of states (80). In this work computer economics dictated that only the more probable sequences be considered. A sum of between 25 and 35% of the total for all possible sequences was found to be representative. The distance traveled in each sequence can be determined by considering each hourly current state as operating for 1 hour, then summing the distances traveled in each hour. A weighted mean distance traveled for the time period in the four primary compass directions can be obtained by combining the sequence probability and distance traveled in that sequence. Estimates of maximum and minimum weighted distances traveled in 5 hours

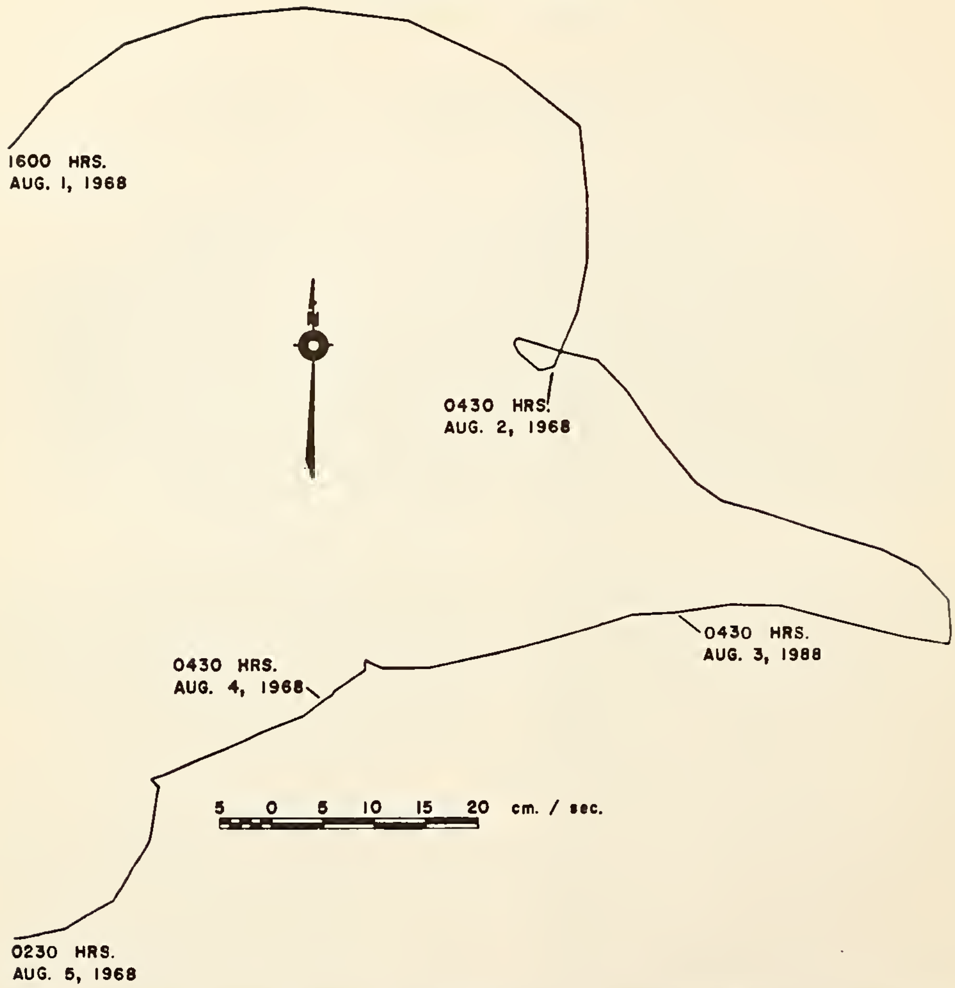


Fig. 1. Successive hourly current vectors occurring at location 022 plotted sequentially head to tail.

can be obtained [*Palmer*, 1970*a*] by considering only the largest and smallest current states with associated probabilities (see Table 1).

If each one of these sequences could be considered as tracing a possible particle path, it would be possible to determine a diffusion coefficient by determining a standard deviation of the weighted distances traveled. To do so, it is necessary to assume that Eulerian measurements approximate Lagrangian determinations. There is some precedence for this assumption in meteorology [*Hay and Pasquill*, 1957; *Lumley*, 1964] and in laboratory pipe flows [*Mickelsen*, 1955] for large Reynolds number, homogeneous and isotropic flow fields. The Reynolds numbers for the lake (the depth being the length parameter) are typically 2×10^6. Spatial homogeneity for a large flow system, such as the lake, have been verified by cross-correlating current time histories for points separated by 1 and 3 km. Correlations for 1-km separation are highly significant. By restricting the hourly considerations to approximately 5 hours (shorter times could also be used), distances traveled are normally less than 1 km. In addition, the auto correlation functions for currents are generally reasonably flat for the first 5 hours. The time period selected should be the one of interest compatible with the current characteristics in the area. On this basis, we

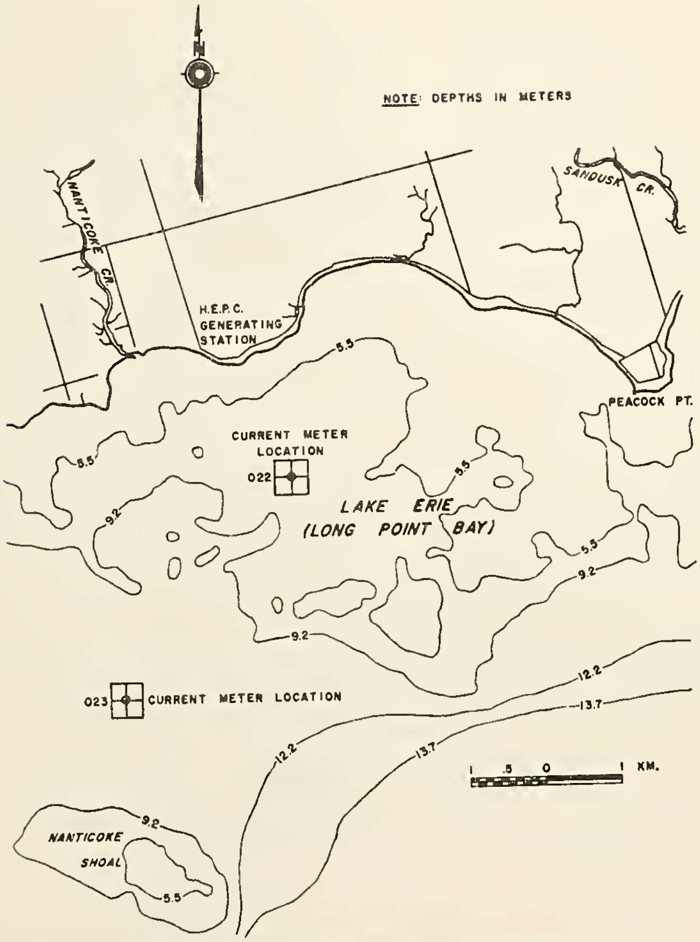


Fig. 2. Recording current meter locations.

decided to assume an equivalence between Eulerian and Lagrangian systems and to compare the results with Lagrangian experiments. A favorable comparison would justify the assumption.

A weighted standard deviation $\langle y^2\rangle^{1/2}$ was determined from the weighted distances traveled. The standard deviation of the sequence of paths in each compass direction can be considered to represent an estimate of the mean 5-hour dispersion characteristics or the mean spread distance of two particles that were released together at the meter, after 5 hours. One standard deviation was obtained for each of the four compass directions (one-dimensional model). From the standard deviations, the 5-hour dispersion coefficients were developed from the following equations [*Hinze*, 1959]:

$$\langle y^2\rangle = 2\epsilon t \tag{1}$$

where

$\langle y^2\rangle$ is the variance of particle separation in cm².
ϵ is the diffusion coefficient in cm²/sec.
t is the time in sec.

This equation is limited to long-term dispersion or distances of the order of 10^7 cm. The short-term form of the equation

$$\langle y^2\rangle = [\langle u_2^2\rangle x_1^2]/\langle U_1^2\rangle \tag{2}$$

where

$\langle u_2^2\rangle$ is the fluctuating velocity in the

TABLE 1. The 5-Hour Distances Traveled by Direction

	North	East	South	West
Location 022 (Figure 2), September 1968				
Probability	0.04	0.50	0.13	0.33
Maximum meters	534	2700	942	2484
Mean meters	385	1010	237	880
Minimum meters	254	51	0	76
Location 023 (Figure 2), September 1968				
Probability	0.03	0.48	0.26	0.23
Maximum meters	331	2484	2340	2340
Mean meters	167	957	270	544
Minimum meters	25	0	0	25

orthogonal direction rms squared in cm^2/sec^2.

$\langle U_1{}^2 \rangle$ is the mean velocity in the principle direction: weighted distance traveled divided by time in cm^2/sec^2.

$x_1{}^2$ is the distance from the source in the principal direction in cm^2.

is restricted to distances less than 10^2 cm. The mean weighted 5-hour distance considered here varies from 1.7×10^2 to 1.4×10^3 cm, which is in the intermediate range between the short- and long-term forms of the equations.

We felt that the long-term form of the equation should be used as the more conservative estimate of dispersion. *Alsaffar* [1966] compiled ocean diffusion measurements made by thirteen oceanographers and developed a best-fit relationship between the diffusion coefficients and spread. Most of the results are contained within an upper limit of

$$\epsilon = 0.09(\langle y^2 \rangle^{1/2})^{4/3} \qquad (3)$$

and the lower limit

$$\epsilon = 0.04(\langle y^2 \rangle^{1/2})^{4/3} \qquad (4)$$

The ϵ results obtained at location 022 in September are compared with Alsaffar's upper and favorably with other studies tending toward the upper limits, which is expected as the results lower limits (see Table 2). *Okubo* [1968] has also summarized two-dimensional dispersion coefficients for the ocean giving the 5-hour range of $(0.3 \text{ to } 2.0) \times 10^4$ cm^2/sec. The results of other Great Lakes results determined by dye experiments are 0.04×10^4 cm^2/sec [*Csanady*, 1964], 3–6 $\times$ 10^4 cm^2/sec [*Noble*, 1961], 0.06×10^4 cm^2/sec [*Okubo*, 1967], and 0.39 $\times$

TABLE 2. Dispersion Coefficients (in cm^2/sec) Location 022 September 1968

	Alsaffar			Palmer
Direction	ϵ	ϵ_{min}	ϵ_{max}	ϵ
North	$4\ 0 \times 10^4$	$2\ 56 \times 10^4$	5.75×10^4	$1\ 28 \times 10^4$
East	$10\ 5 \times 10^4$	4.48×10^4	10.1×10^4	$72\ 0 \times 10^4$
South	$3\ 9 \times 10^4$	$2\ 32 \times 10^4$	$5\ 23 \times 10^4$	$1\ 28 \times 10^4$
West	$12\ 0 \times 10^4$	$4\ 84 \times 10^4$	$11\ 0 \times 10^4$	$72\ 0 \times 10^4$

10^4 cm^2/sec [*Murthy*, 1969]. With the exception of Murthy's results, the dispersion coefficients were not measured explicitly as functions of time. In general, the other experiments were over a period of 4 to 8 hours. The dispersion coefficients obtained by this method compare are for a position close to shore in reasonably shallow water. Further, the dispersion coefficients obtained here are an order of magnitude less than the monthly coefficients [*Palmer*, 1970*b*]. This is expected on the lakes because the hourly period does not include the full effect of large-scale occurrences such as lake and bay wind seiches which would contribute to the dispersion characteristics.

To obtain measures of the dilution characteristics in each direction after 5 hours, it is necessary to incorporate the dispersion coefficient in an appropriate dispersion equation. Many equations are not suitable because the terms cannot be determined from the information obtained from a Markov process analysis. *Batchelor* [1949] proposed a one-dimensional diffusion model from a continuous point source [*Foxworthy et al.*, 1966].

$$\langle C_{max}(x) \rangle = \frac{Q}{(2\pi)^{1/2} \langle y^2 \rangle^{1/2} \langle U \rangle} \qquad (5)$$

where

$\langle C_{max}(x) \rangle$ is the maximum mass in mg/cm^2.

Q is the mass discharge in mg/sec.

$\langle y^2 \rangle$ is the weighted mean spread in cm^2.

$\langle U \rangle$ is the weighted mean velocity in cm/sec.

By applying equation 5, with a discharge rate of 78,000 cm^3/sec and with $\langle C_{max} \rangle / \langle C_{max} \rangle$ (north), the dilution occurring in each direction is: north, 100%; east, 7.2%; south, 38.0%; and west, 5.5%. The flow equation (5) is selected to illustrate the relative difference of short-term dilution rates for each direction.

TABLE 3. The 5-Hour Mean Standard Deviations (in cm)

Location	South	West	North-	East
Meter 022-				
Sept.	3.74×10^4	6.52×10^4	3.92×10^4	6.13×10^4
Oct.	6.10×10^4	9.9×10^4	4.1×10^4	9.7×10^4
Meter 023				
Sept.	1.94×10^4	8.34×10^4	5.14×10^4	6.58×10^4
Oct.	7.50×10^4	11.6×10^4	7.0×10^4	9.23×10^4

A summary of the results for the short-term 5-hour mean variances (particle spread) for different locations and times are presented in Table 3.

LAGRANGIAN VERIFICATION

The method of determining hourly dispersion characteristics from current meters was applied to a study at the outlet of the Grand River, Port Maitland, on the northeast shore of Lake Erie in September 1969. A recording current meter was installed 1.2×10^3 meters southwest of the river outlet at the mid-depth in 11 meters of water, where it was operated from September 2 to September 18. The dispersion characteristics determined from this current meter record are presented in Table 4.

A short-term dye injection run was conducted on September 8. Rhodamine B dye was injected continuously at a constant rate (continuous constant rate point source) at the mid-channel point 2 meters below the surface in the river outlet for approximately 8 hours. The dye plume came from a northwesterly direction (went to the southeast). Once equilibrium conditions (steady state) were achieved 1000 meters from the source, concentration profiles were measured in two dimensions (parallel to the water surface and at various depths) at five selected cross sections. Details of the method are outlined in *Foxworthy et al.* [1966] and *Palmer* [1969]. Mass-flow balances were computed from the concentration profiles and simultaneous drogue studies for velocity measurements. Unfortunately, three of the five cross sections were incomplete with mass flows less than 75% of the continuous constant injection rate at the point source. These cross sections could not be used to compute dispersion characteristics. Standard deviations of spread were computed from the concentration distributions measured parallel to the water surface at the two acceptable cross sections [*Foxworthy et al.*, 1966]. The results of the two cross sections are plotted in Figure 3. If the mean velocity $\langle U \rangle$ for the north and west direction from Table 4 is used to compute the 5-hour distance traveled, a value of 120 meters is obtained. A linear relationship has been found between log $\langle y^2 \rangle^{1/2}$ and log (distance from the source) [*Foxworthy et al.*, 1966; *Palmer*, 1969]. The extrapolated 5-hour standard deviation $\langle y^2 \rangle^{1/2}$ for 120 meters from Figure 3 is 2.50×10^3 cm, whereas the mean standard deviation from the northwest direction from Table 4 (averaging north and west values) is 9.00×10^3 cm. The dispersion predictions obtained from the current meter records are the most probable for each of the major compass directions, whereas the dye experiment is a

TABLE 4. Port Maitland 5-Hour Dispersion Characteristics, September 1969

Direction	$\langle y^2 \rangle^{1/2}$, cm	U, cm/sec
North	1.33×10^4	0.960
East	1.19×10^4	0.715
South	1.42×10^4	0.932
West	0.461×10^4	0.362

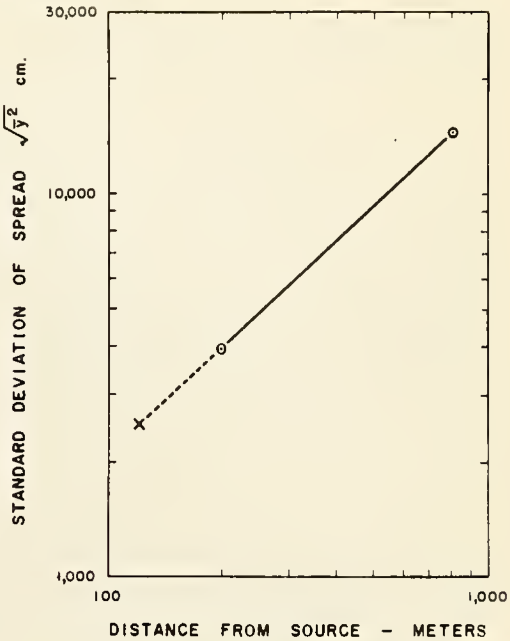


Fig. 3. Port Maitland, Grand River at Lake Erie, dye dispersion run, September 1969.

single determination in one direction. The good agreement between the two methods justifies the Eulerian to Lagrangian conversion.

CONCLUSIONS

The hourly dispersion method outlined provides a means of determining particle movements and mean dispersion characteristics from current meter records. The assumption of equivalence between Eulerian and Lagrangian measurements appears reasonable for a few hours off shore in large lake flow systems. The high degree of variability of the water movements when considered over short periods of time and different locations necessitates the probability and mean 5-hour approach. It is now possible to compare the short-term dispersion pattern for each compass direction. The method further provides an indication of the maximum and minimum distances likely to be traveled in any 5-hour period.

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(Received August 13, 1970;
revised October 23, 1970.)

Proc. 13th Conf. Great Lakes Res. 1970:
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LAKESHORE TWO-DIMENSIONAL DISPERSION

M.D. Palmer and J.B. Izatt

Great Lakes Surveys, Ontario Water Resources Commission, Toronto, Ontario

Abstract. Hourly two-dimensional dispersion characteristics are determined from recording current meter histories for the nearshore areas on Lakes Erie and Ontario. The current histories were obtained in areas within 4 km of shore and at water depths of 10 to 14 m during May to November 1968. A Markov chain process was applied to hourly current readings. Three different formulations of the stochastic process were tested prior to the selection of the most reliable one. The results obtained in applying the developed technique compare favourably with results obtained from conventional dye injection and drogue studies. (Key words: Currents; diffusion; instruments and techniques.)

INTRODUCTION

Measurements of the nearshore currents in the Great Lakes have revealed the highly variable nature of the water movements in both time and space. As the currents are the basic mechanism responsible for dispersion, it is necessary to understand and develop analytical techniques to describe the water movements. The problem can be simplified by considering different time and spatial scales separately. This technique has been used in air pollution studies (Hilst, 1968), estuarine analysis (Okubo, 1964) and Great Lakes Studies (Palmer, 1969). In the Great Lakes studies, monthly average dispersion and 5 hr dispersion characteristics were developed from the continuous history of currents measured at a fixed point every 10 min and averaged to hourly values. The 5 hr diffusion characteristics were determined after lengthy analysis on the computer for the four major compass directions. However, the computations are seriously limited to time periods not greater than 5 hr and major compass directions by computer time and core space considerations. This represents a serious limitation if the technique is to be incorporated as an integral step into a larger assimilation model. The purpose of this paper is to outline alternate methods for determining hourly two-dimensional dispersion characteristics from current meter records for depths of water 10 to 14 m within 4 km of the shore. These methods require a fraction of the computer time compared to the other method (Palmer, 1969). The methods also produce maximum, mean and minimum dispersion characteristics with the associated probabilities for eight major compass directions and various time periods.

DEVELOPMENT OF METHOD*

From the continuous hourly current records for a month, it is possible to obtain a one-hour state probability transition matrix. The currents are first classified into 80 designated current states (8 directions and 10 speed intervals) as outlined in Table 1.

*The following symbols are used in the text: ϵ = two-dimensional dispersion coefficient cm^2/sec; σ^2 = variance cm^2; qn(k) = final state probability vector after "k" hours; qm = initial state probability vector; T^i mn (k) = state transition probability matrix for "k" hour intervals between readings raised to the power "i".

TABLE 1. State number index.

	Direction				
Magnitude	337.5° to 22.5°	22.5° to 67.5°		247.5° to 292.5°	292.5° to 337.5°
0 - 2 cm/sec	1	9	—	7	8
2 - 4 cm/sec	9	10	—	15	16
—					
—					
—					
16 - 18 cm/sec	65	66	—	71	72
18 - 20 cm/sec	73	74	—	79	80

The velocity intervals can be varied to suit the measured velocity ranges. An initial state probability vector "q" for the month can be obtained. The initial state probability vector "q" is the probability of occurrence of each state for the month. A transitional state probability matrix can be developed. As an example, suppose a loaded die was thrown 1000 times and a record was kept of the results. There are six possible outcomes, called states, on each throw; namely one, two, three --- or six. Suppose a two is case, it is possible to determine the probability of all the other possible states occurring on the next throw by examining the record to obtain what states followed a two state and how often it occurred. A different set of probabilities would be obtained by considering a different start of initial state; namely one, or three. Considering all possibilities produces a transitional state probability matrix six by six. The one-hour state probability transition matrix can then be obtained from the analysis of the current histories classified into states (Palmer, 1969). A sample of the resulting 80 x 80 transition matrix appears in Table 2A. Hence by selecting an initial current, a row is specified and the probability of any state 1 hr later may be found by looking at the intersection of that row and the appropriate column. For example, the first element of block "A" represents the probability of going from a state of 0-2 cm/sec and 337.5° to 22.5° to a

TABLE 2A. One hour transition probability matrix. Each block represents an 8 x 8 matrix and a sample representing block "A" may be found in Table 2B.

			Final state			
	SPEED		0 to 4 cm/sec		2 to 4 cm/sec	
		ANGLE	337.5° to 22.5°	292.5° to 337.5°	337.5° to 22.5°	292.5° to 337.5°
Initial State	0 to 2 cm/sec	337.5-22.5				
		— —			A	
		— —				
		— —				
		292.5-337.5				
	2 to 4 cm/sec	337.5-22.5				
		— —				
		— —				
		— —				
		292.5-337.5				

etc.

TABLE 2B. One hour transition probability matrix.

		Final state 2.0 to 4.0 cm/sec			
		337.50° to 22.5°	22.5° to 67.5°	—	292.5° to 337.5°
Initial State 0 to 2.0 cm/sec	337.5° to 22.5°	0.01737	0.00668	—	0.00240
	22.5° to 67.5°	0.00634	0.01692	—	0.00121
	—	—	—	—	—
	—	—	—	—	—
	—	—	—	—	—
	292.5° to 337.5°	0.00626	0.00521	—	0.01147

state of 2-4 cm/sec and 337.5° to 22.5°.

Three alternate methods were developed using the above techniques to predict dispersion characteristics. As a first step, it was necessary to develop the state probability vector after a certain number of hours given the initial state vector and the continuous current meter records. The three approaches involve different methods of determining this final state vector but use the same method of predicting the dispersion characteristics.

The first method involved combining the initial state probability vector "q_m" for the month (essentially a frequency analysis of a month's current meter record by states) with various powers of the one hour transition probability matrix "$T^i_{mn}(1)$" where "i" represents the power of the matrix (Bharucha-Reid, 1960; Kemeny, 1962).

$$q_n(k) = \sum_{m=1}^{80} q_m \, T^i_{mn}(1) \qquad (1)$$

where q_n = final state probability vector after "k" hours. "n" is the final state.

q_m = initial state probability vector. "m" is the initial state.

$T^i_{mn}(1)$ = one hour state transition probability matrix raised to "i^{th}" power where i = k.

The obvious weakness of this method is that any errors present in the first power of the transition matrix will be propagated and intensified by the process of raising the matrix to power "i".

The second alternative method involves the use of several first order transition matrices based on varying the intervals between successive currents used in computing the matrix. For example, a matrix could be found by considering only the probability of transitions involving every fifth hourly reading and hence a first order matrix for 5 hr could be found. These matrices could then be combined with the initial state vector to give the final state vector after any given number of hours.

$$q_n(k) = \sum_{m=1}^{80} q_m \, T_{mn}(k) \qquad (2)$$

where q_n (k) = final state probability vector after "k" hours. "n" is the final state.

q_m = initial state probability vector. "m" is the initial state.

$T_{mn}(k)$ = state probability transition matrix after k = 1,2,3 --- hr.

This method avoids the necessity of raising the transition matrix to higher powers and thus eliminates errors found in the previous method. However, computer time increases substantially when it becomes necessary to search the monthly records many times to establish the various first order matrices. The method is weakened somewhat in theory because a first order Markov chain implies that a result is dependent only on the directly preceding result. While it is known that currents occurring in a particular hour are related to currents occurring 1 hr previously, the relationship of currents separated in time by 5 or 8 hr is dependent on the physical size of the area as well as the driving force. It is not possible to state, as a general rule, that the current occurring now is dependent on the current which occurred 5 hr earlier.

The final method tested avoided the weakness of the previous two methods. The initial state vector and the transition matrix are defined as in the first method. However, the higher order final states are computed using the final state vector for the previous hour as the initial state vector for the present computation. For instance, the final state vector for the first hour would be multiplied by the first order one-hour transition matrix to give the final state vector for the second hour (Gablinger, 1970).

$$q_n (k) = \sum_{m=1}^{80} q_m (k-1)\ T_{mn} (1) \qquad (3)$$

where q_n (k) = final state probability vector after "k" hours

$q_m(k-1)$ = final state probability vector after "k-1" hours

$T_{mn}(1)$ = one hour state probability transition matrix.

This method directly relates the results of one time period to subsequent time periods.

The question of how many hours must be considered for short term dispersion characteristics can be resolved by determining the number of hours required to approach a monthly mean. In figures 1 and 2, the state probabilities are plotted against the various states for west and north respectively. The monthly mean state for the west direction obtained from a frequency analysis of the monthly record is State 23. Figure 1 demonstrates the tendency of the most probable state to approach State 23 by the eighth hour, whereas a most probable state for the north direction is State 1 which is achieved in the first and successive hours. As the various directions at a particular location are related, it is necessary to consider the longest time interval required to approach mean conditions in any direction. It has been found that a period of 8 hr is a

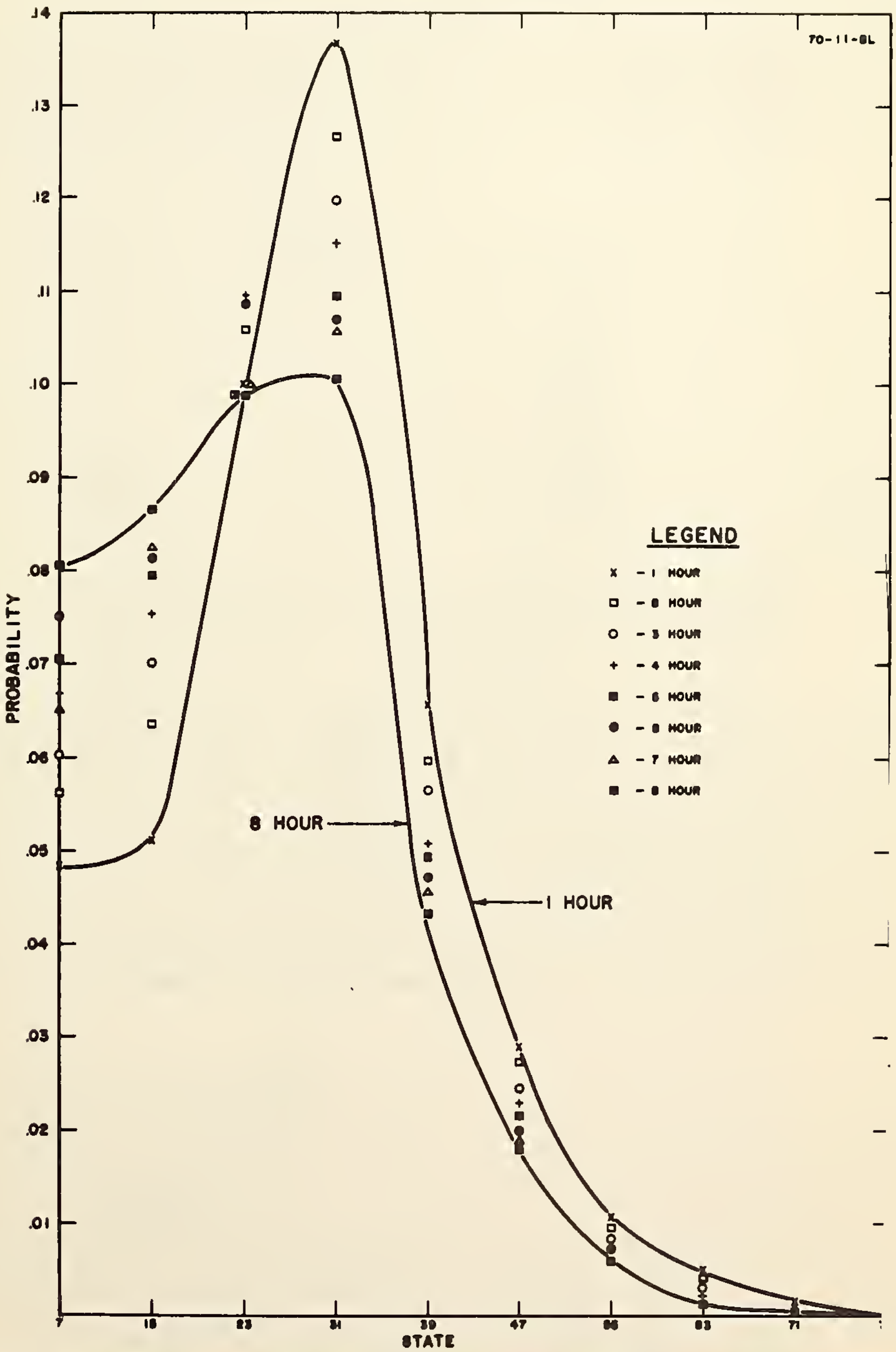

FIG. 1. State probability distribution for Nanticoke, September 1968 in west direction.

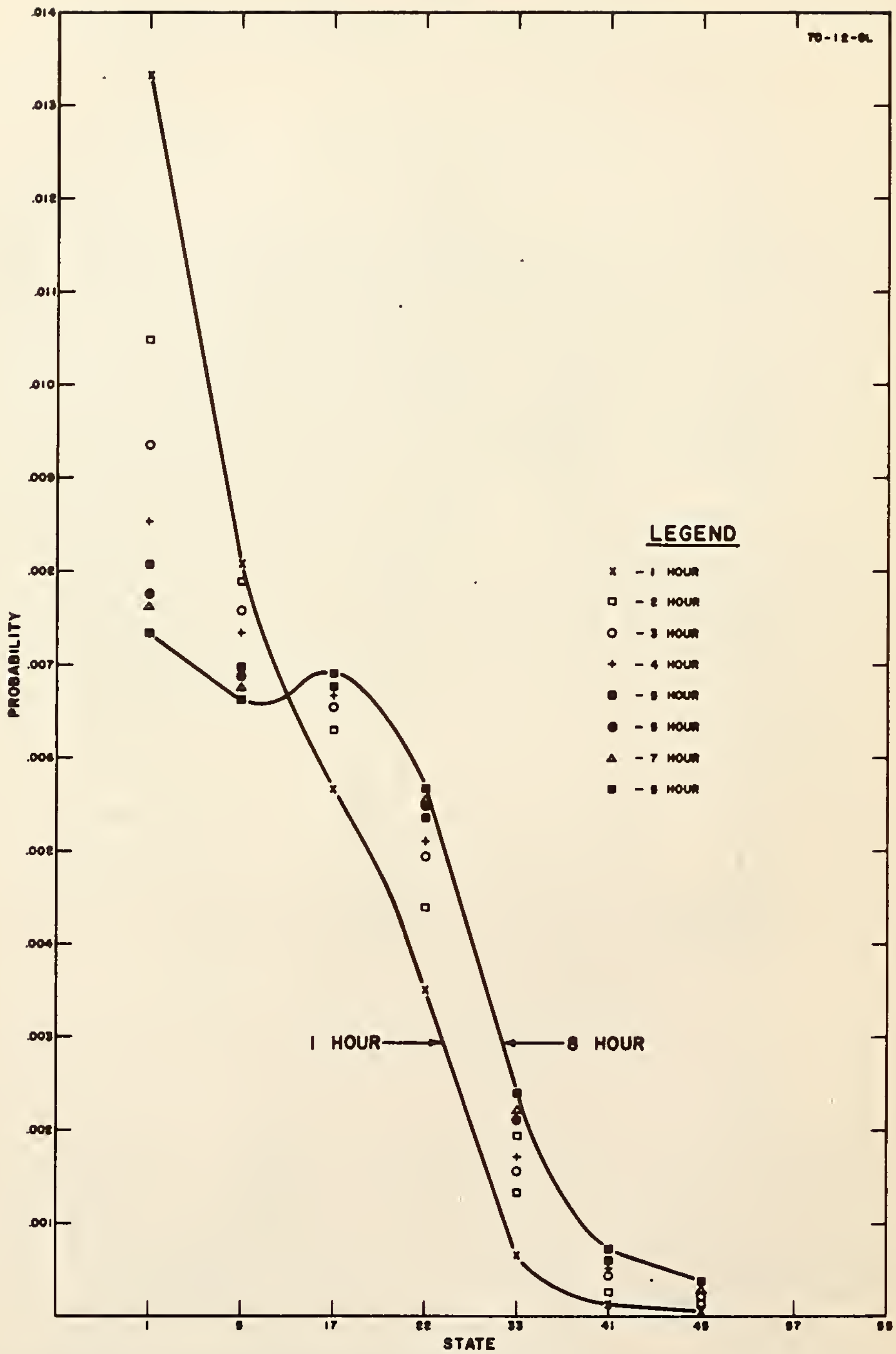

FIG. 2. State probability distribution for Nanticoke, September 1968 in north direction.

judicious time interval for short term dispersion characteristics.

A measure of the dispersion characteristics for each hourly interval can be obtained by using the state probability for that time interval as weighting factors. The weighting factors multiplied by the respective states and extended to the time interval considered will generate the most probable distances travelled in the eight major compass directions for the time period considered. As an example, the distance travelled in the south direction after one hour is computed as follows:

State	Mean Velocity cm/sec	Probability	
(A)	(B)	(C)	(B) x (C)
1	1	0.0132	0.0132
9	3	0.0081	0.0162
17	5	0.0057	0.0285
25	7	0.0034	0.0238
33	9	0.0009	0.0081
41	11	0.0002	0.0021
49	13	0.0001	0.0013
		Sum =	0.0932

Most probable distance travelled after one hour $= 0.0932 \times 60 \times 60$
$= 336$ cm

A comparison of the results by using Eq. 1, 2 and 3 for the mean 8 hr pattern appears in Fig. 3. It is observed that there is little difference in employing the three methods although the third method was selected as being the more reliable when considering the propagation of errors. A plot of the successive hourly patterns produced by the third method appear in Figs. 4 and 5 for a location on Lake Erie and Lake Ontario respectively. The areas defined by the various related hourly contours are representative of the dispersion characteristics for that time period. The patterns *do not* represent actual dispersion plumes as the probabilities have been combined with distances travelled in any time period. The areas are representative fo the variance "$\sigma 2$". An apparent two-dimensional dispersion coefficient "ϵ" can be defined (Okubo, 1968).

$$\epsilon = \frac{1}{4} \frac{\sigma 2}{t} \tag{4}$$

A sample of the dispersion coefficients computed in this manner and summary of results presented by Okubo (1968) for an instantaneous point dye release appear in Table 3.

A length scale "1" can be defined as the square root of the area. If log ϵ is plotted against log 1 for the values in Table 3, a straight line with a slope of 1.23 is obtained. The slope is slightly less than that predicted by "Richardson's 4/3 law". Ozmidov (Okubo, 1968) explained that the growth rate is normally less than 4/3 due to energy being added by wind systems and tidal currents. A comparison of the diffusion coefficients obtained by this method with results from other studies without time scale appears in Table 4.

The two-dimensional diffusion coefficients computed from recording current meter data compare favourably both in magnitude and functional re-

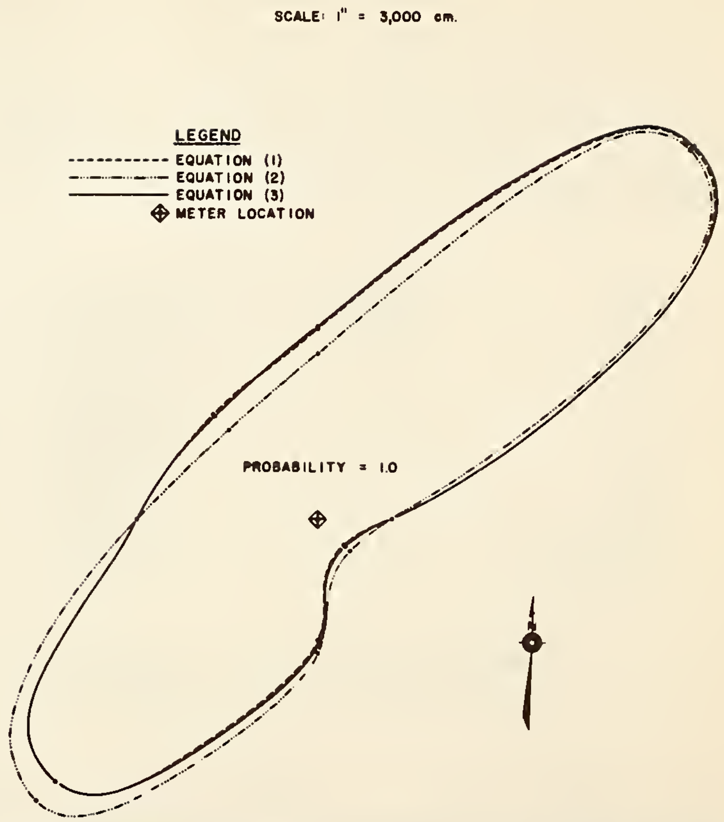

FIG. 3. Comparison of mean weighted 8 hr dispersion patterns determined from Eq. 1, 2 and 3 for Nanticoke, September 1968 at 4 m below the surface.

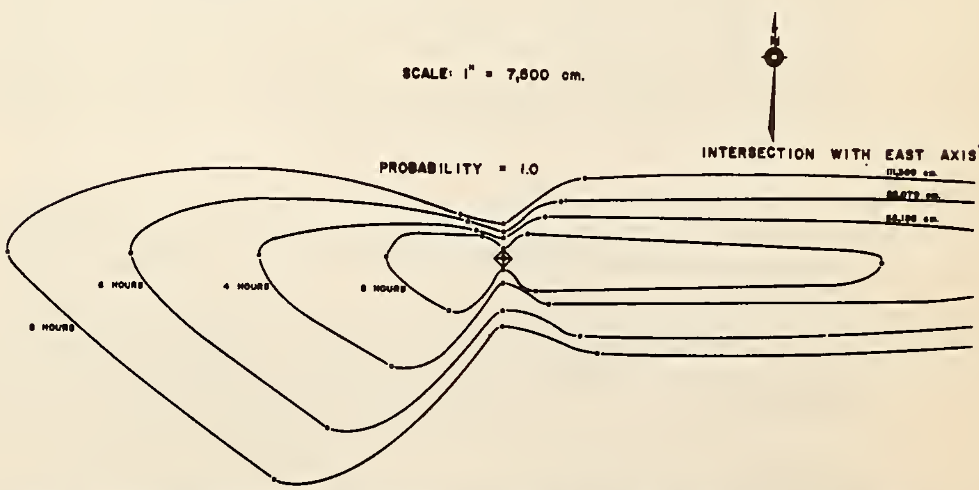

FIG. 4. Mean weighted hourly dispersion patterns for Nanticoke, September 1968 at 4 m below the surface.

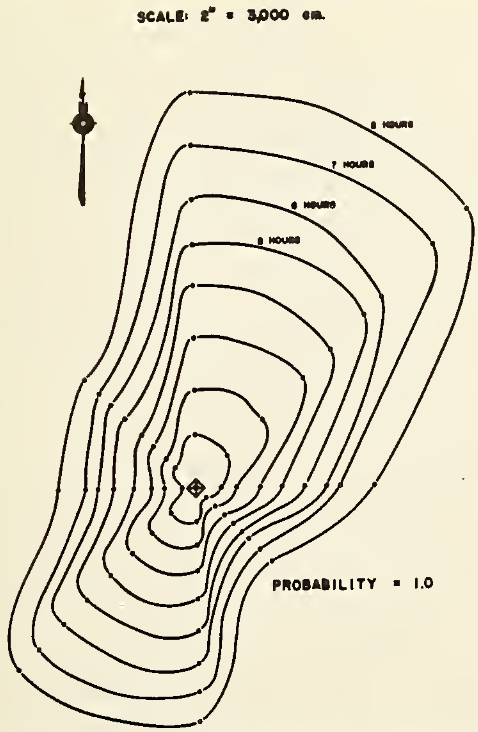

FIG. 5. Mean weighted hourly dispersion patterns for Frenchman Bay, June 1968 at 12 m below the surface.

TABLE 3. Diffusion coefficients for Nanticoke, September 1968.

Time hours	ε Diffusion coefficients cm^2/sec	
	Nanticoke	Okubo, 1968 Fig. 6, p. 23
1	0.167×10^4	0.02 to 0.19×10^4
2	0.40×10^4	0.14 to 0.83×10^4
3	0.928×10^4	
4	1.43×10^4	0.14 to 1.4×10^4
5	2.08×10^4	
6	2.78×10^4	
7	3.48×10^4	
8	4.35×10^4	

TABLE 4. Results of other studies varying times.

Reference	(cm^2/sec)
Csanady (1964)	4×10^2 (one at 2×10^3)
Okubo (1967)	3 to 6×10^4
Noble (1961)	2.44×10^2

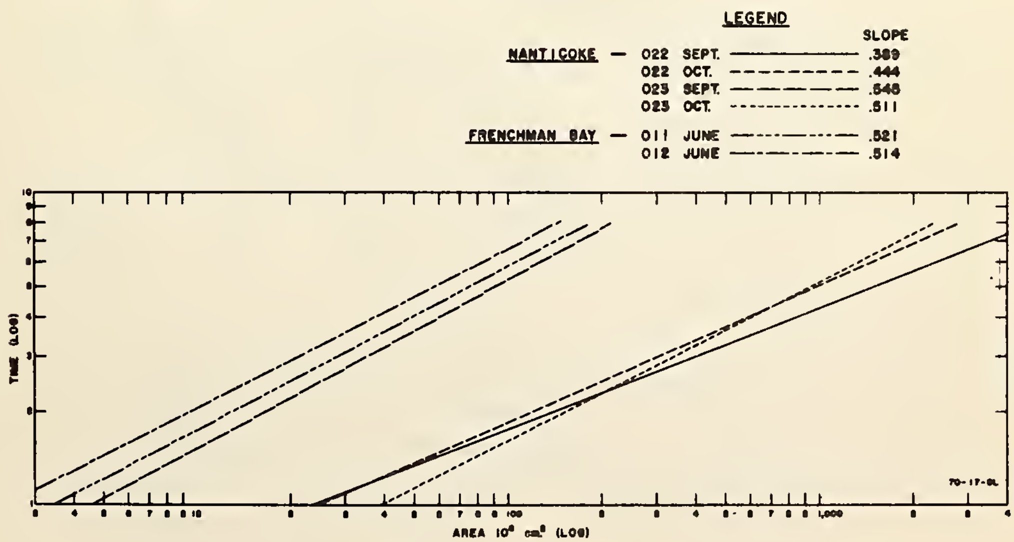

FIG. 6. Mean dispersion areas.

lationship with time to instantaneous point dye studies and drogue trackings. The mean conditions for four different locations on Lakes Erie and Ontario appear in Fig. 6. It is observed that a power relationship exists between the log (time) and the log (area). This is a similar situation determined by Okubo (1964), in his estuarine study, where the diffusion coefficient increases with distance and time are directly related. The power varies from .389 to .545 which indicates the dependence of diffusion on both the local topography and the time of year.

It is also possible to obtain a measure of the minimum and maximum likely dispersion characteristics from the meter records. This can be achieved by considering various portions of the state probability vector at the end of various time intervals. For instance, a measure of the minimum dispersion characteristics could be obtained by considering only states 1 to 8. The probabilities for these states can be summed and weighting factors can be obtained by increasing the probabilities to sum to one. The distances travelled for each time interval can then be obtained by multiplying the weighting factors by the state velocity intervals and the appropriate time intervals considered. The probability of this condition is defined by the sum of the original probabilities for these states. Similarly, a maximum condition can be determined by considering only states above State 41 and performing a similar operation to determine the weighting factors. A selection of the states to be considered for minimum and maximum condition will obviously be dependent upon the current history for a particular area. A comparison of the results for Eq. 1, 2 and 3 for the minimum and maximum 8 hr patterns appears in Figs. 7 and 8. For the minimum, there is little difference between the three methods, however, Eq. 2 does generate a significantly different pattern for the maximum condition. There are some theoretical problems in selecting method two (Eq. 2) and the third method (Eq. 3) was selected to determine minimum and maximum as well as the mean

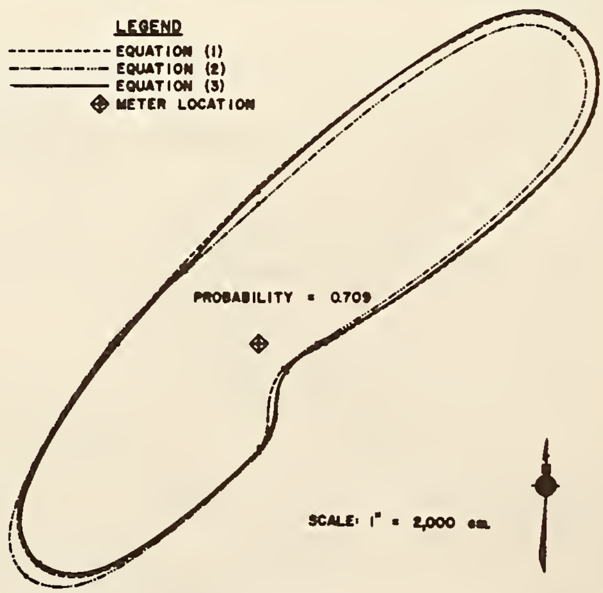

FIG. 7. Comparison of minimum weighted eight hour dispersion patterns determined from Eq. 1, 2 and 3 for Frenchman Bay, June 1968 at 9 m below the surface.

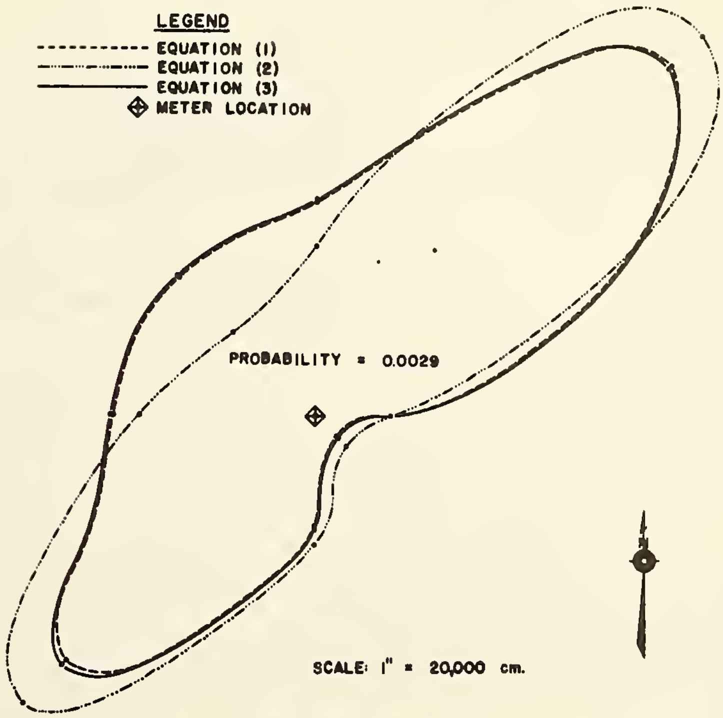

FIG. 8. Comparison of maximum weighted eight hour dispersion patterns determined from Eq. 1, 2 and 3 for Frenchman Bay, June 1968 at 9 m below the surface.

TABLE 5. Eight hour area comparisons.

	Method		
	Equation 1 x 10^7 cm^2	Equation 2 x 10^7 cm^2	Equation 3 x 10^7 cm^2
Minimum	5.2	4.5	4.7
Mean	14.0	10.2	14.4
Maximum	6,600	5,200	6,000

patterns. The results of applying Equations 1, 2 and 3 to the data to determine minimum, mean and maximum 8 hr dispersion patterns appear in Figs. 3, 7 and 8. The areas defined by the different methods appear in Table 5.

Examples of the maximum and minimum conditions found using the third method mentioned above for an 8 hr period appear in Figs. 9 and 10. Once again, the area is defined by the various hourly contours which are representative of the dispersion characteristics. The areas defined by this method appear in Fig. 11 for the maximum and minimum power at four different locations on Lakes Erie and Ontario. It will be noticed that a power relationship exists once again for a maximum and minimum condition, but that the slopes do not vary as widely as those of the mean, although the intercepts are more variable.

SUMMARY AND CONCLUSIONS

The Markov chain analytical technique has been demonstrated as a reasonable method for determining two-dimensional dispersion characteristics

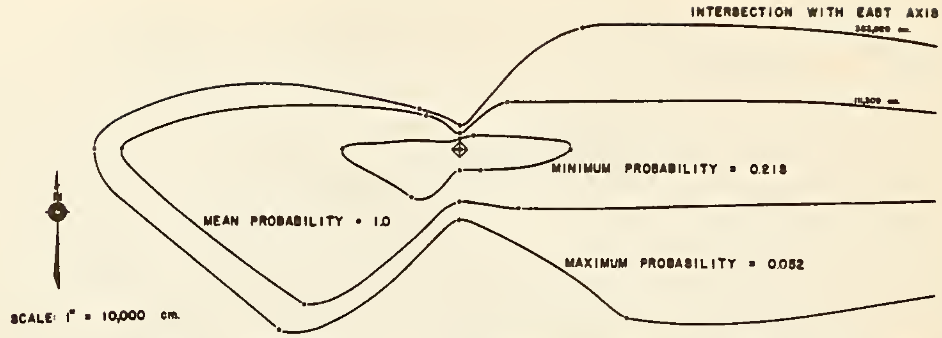

FIG. 9. Comparison of minimum, mean and maximum dispersion patterns for Nanticoke, September 1968 at 4 m below the surface.

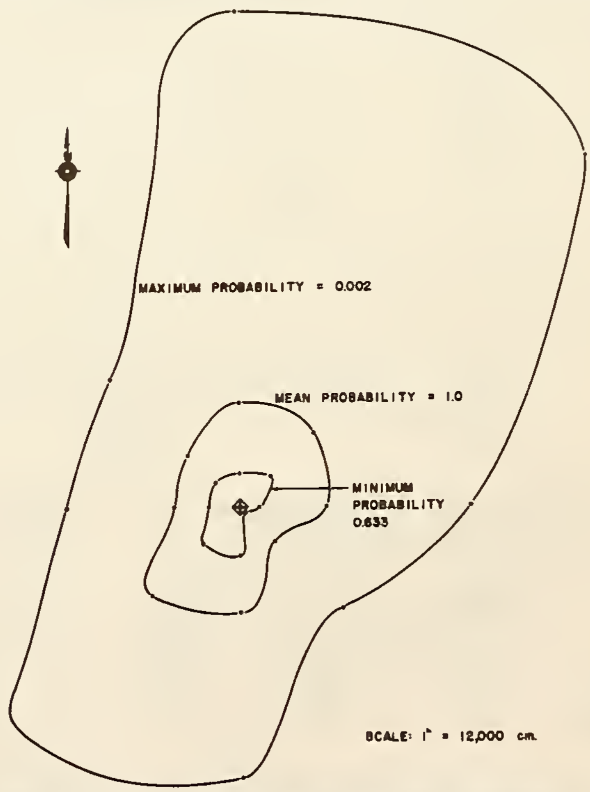

FIG. 10. Comparison of minimum, mean and maximum dispersion patterns for Frenchman Bay, June 1968 at 12 m below the surface.

from recording current meter data. The figures of patterns *do not* represent actual plumes. It has been tested in three different forms, namely, the development of higher order chains utilizing the power of first order chains, higher order chains developed for different time intervals, and step wise, first order Markov chains applied hour after hour. The latter technique has been found to be the most reliable in predicting hourly two-dimensional hourly dispersion pat-

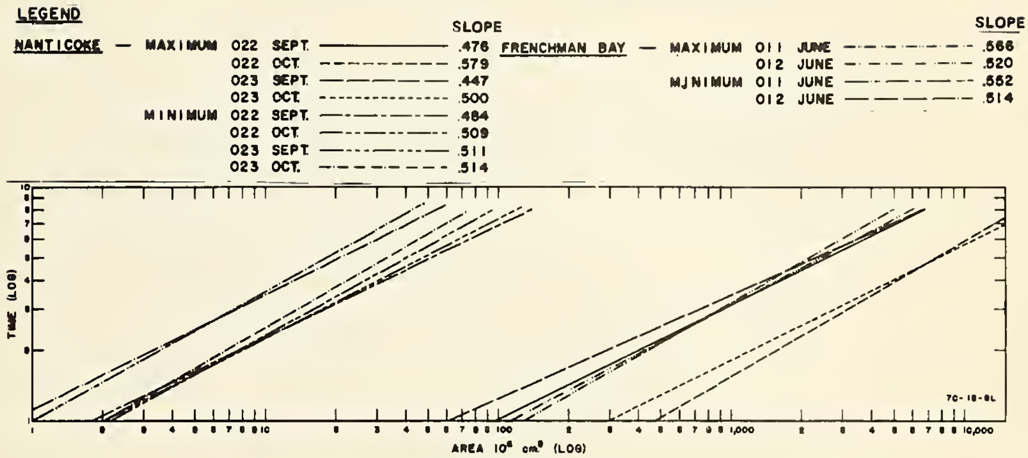

FIG. 11. Minimum and maximum dispersion areas.

terns. However, the difference between the three methods is, in most cases, negligible. The results obtained by employing the Markov process compare favourably with dispersion characteristics determined by conventional techniques, such as dye dispersion runs and drogue trackings. Further, the Markov chain process can be particularly useful in determining the limits of short term (hourly) dispersion characteristics.

A linear relationship exists between the log (time) plotted against the log (area) with slopes varying from 0.389 to 0.579 and intercepts varying 0.026 to 1.1 hr. This is a similar result determined for estuarine dispersion. No significant relationship could be developed relating diffusion characteristics with month or geographic location from these data. The highly variable nature of the nearshore area dispersion characteristics of lakes was confirmed.

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Journal of the
HYDRAULICS DIVISION
Proceedings of the American Society of Civil Engineers

DISPERSION PREDICTION FROM CURRENT METERS

By Mervyn D. Palmer,[1] A. M. ASCE and J. Bryan Izatt[2]

INTRODUCTION

Recorded current meter data were collected in the Nanticoke area on Lake Erie during 1968 as part of a detailed water environment study. Previous work applied standard time series methods to determine energy spectra of currents, temperatures, and water levels, as well as the correlations of these parameters (9). This work provided detailed information on the water movements and temperatures in the area as well as the physical forces responsible for these phenomena. There was also a need to develop dispersion relationships for passive contaminants introduced into the area to permit the assessment of the effects of a source of pollutants on the local environment. Passive contaminants are non-decaying water soluble constituents which have negligible molecular transport and do not affect the physical transport due to water movements. Outlined herein is a method for the prediction of dispersion relationships based upon recorded meter data. The terms used in the method originate from turbulence studies and are defined where necessary. Intermediate steps have been omitted to permit a concise presentation.

METHOD DEVELOPMENT

J. O. Hinze (4) presented various forms of dispersion equations for different types of flow fields. All of the equations contain terms representing turbulence characteristics, distances from sources and mean velocities where applicable. The problem is to select the appropriate equations for the Nanticoke area.

Measured velocities using current meters are two-dimensional: conse-

Note.—Discussion open until January 1, 1971. To extend the closing date one month, a written request must be filed with the Executive Director, ASCE. This paper is part of the copyrighted Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, Vol. 96, No. HY8, August, 1970. Manuscript was submitted for review for possible publication on September 11, 1969.

[1]Environmental Eng., WQSB, (Water Quality Surveys Branch) Dept. of San. Eng., Ontario Water Resources Commission.

[2]Eng., WQSB, Dept. of San. Eng., Ontario Water Resources Commission.

quently, any relationship describing the dispersion characteristics will have to be two-dimensional. This is not a serious limitation, as the maximum depth in the study area is only 13 m. Provided the long-term distribution of a passive contaminant is considered, the distribution with depth will be nearly uniform compared to the horizontal (parallel to the water surface) distribution. Energy spectra for the north-south and east-west correlations between meter locations indicated that the dispersion characteristics for the north-south and east-west directions are different. Therefore, the applicable expression must

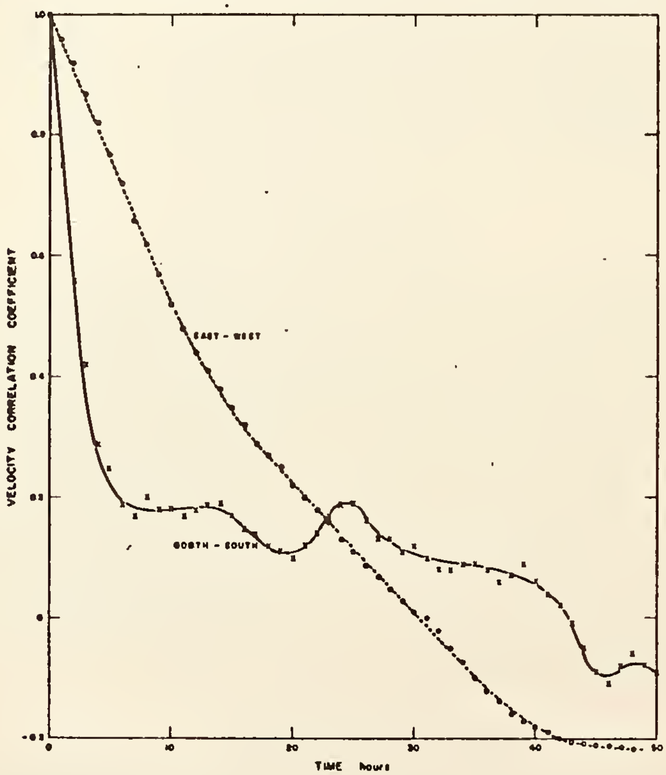

FIG. 1.—AUTOCORRELATIONS: SEPTEMBER, 1968 (meter 023)

differentiate between the components. One equation that meets these requirements is:

$$P(x_1, x_2) = \int_0^\infty dt \frac{S}{(2\pi)^{3/2} (\overline{y_1^2}\ \overline{y_2^2})^{1/2}} \exp\left\{-\frac{1}{2}\left[\frac{(x_1 - \overline{U}_1\ t)^2}{\overline{y_1^2}} + \frac{x_2^2}{\overline{y_1^2}}\right]\right\} \quad (1)$$

[(4) p. 327] in which x_2 = distance from source in north-south direction in cm positive in the direction of the resultant vector component; x_1 = distance from source in east-west direction in cm positive in the direction of the resultant vector component; S = continuous point source cm² per sec per unit depth; $\overline{y_1^2}$ = variance of the displacement in the east-west direction in cm²; $\overline{y_2^2}$ = vari-

ance of the displacement in the north-south direction in cm²; $\bar{U}_1$ = resultant velocity in cm per sec; $P(x_1, x_2)$ = probability of finding a marked fluid particle at a point x_1, x_2; and t = time in sec. Eq. 1 is a special solution of the general equation [(4) p. 325]:

$$-\bar{U}_1 \frac{\partial P}{\partial x_1} = \epsilon \frac{\partial^2 P}{\partial x_i \, \partial x_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

in which ϵ = the diffusion coefficient. This is the classical diffusion equation for molecules and heat in an isotropic medium which states that quantities move down concentration gradients. The diffusion coefficient is a function of

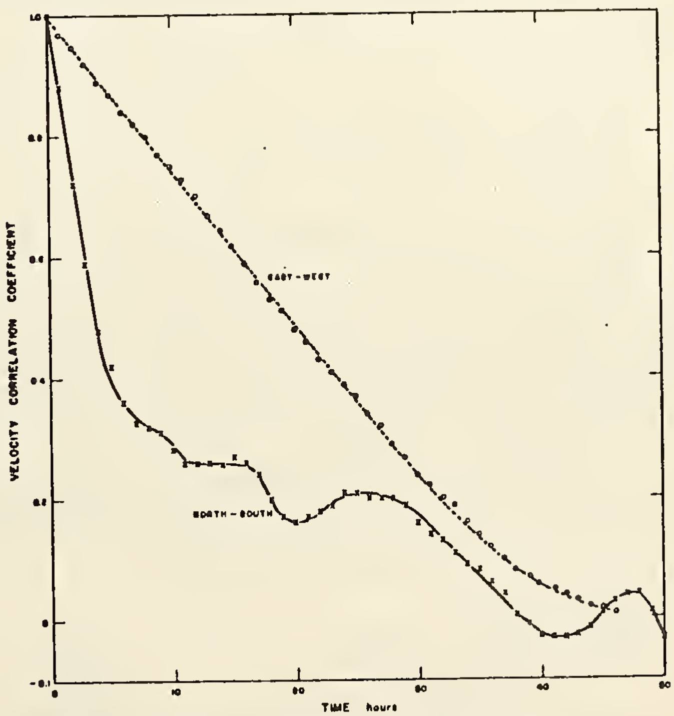

FIG. 2.—AUTOCORRELATIONS: SEPTEMBER, 1968 (meter 022)

direction only for the particular time period under analysis. To obtain dispersion plumes from the two-dimensional (north-south and east-west) current meter records, it is necessary to assume that the dispersion is described by the two horizontal diffusion coefficients, and that the coefficients remain constant throughout the plume. The first assumption of two-dimensionality is not serious, provided that reasonably long time periods are considered so that the distribution with depth is uniform, or conversely that the distances are far enough from the source such that the depth scale of 13 m is not significant. The second assumption that the diffusion coefficients are reasonably constant with distance from the source can be justified by developing the coefficients

as long time averages and invoking the condition that the velocity field is reasonably uniform over areas of 4 km. The uniform velocity field assumption has been verified at Nanticoke by the time series analysis of velocities which revealed significant correlations between currents measured at 022 and 023 (9). It was decided to restrict the assumption of constant diffusion coefficient to distances of 5×10^5 cm or 50 integral scales (5). For short times (4) in which $\tau < \zeta_L$; τ = time; and ζ_L = Lagrangian integral scale.

$$\overline{y_i^2} = \frac{\overline{u_i^2}\, x_j^2}{\bar{U}_1^2} \quad \text{(3)}$$

in which i = 1, 2; j = 2, 1; and $\overline{u_i^2}$ = fluctuating velocity root mean square squared in i direction in sq cm² per sec²; and x_j^2 = distance from source in j direction in cm. For long times (Ibid) in which $\epsilon/\bar{U}_1 x_1 \ll 1$

$$\overline{y_i^2} = \frac{2\, \epsilon_i\, x_j}{\bar{U}_1} \quad \text{(4)}$$

and the assymptotic condition (4)

$$\epsilon_i = u_i' \, (\Lambda_L)_i \quad \text{(5)}$$

u_i' = fluctuating velocity root mean square in i direction in cm per sec; and $(\Lambda_L)_i$ = Lagrangian integral scale in i direction in cm. As the meters are fixed, the velocity data is Eulerian, not Lagrangian. The relationship between Eulerian and Lagrangian systems is very complex. However, the following approximate relationship has been found between the Eulerian integral time scale and Eulerian integral space scale (4,5) $\Lambda_E \approx \bar{U}\, \zeta_E$; in which Λ_E = Eulerian integral space scale; and ζ_E = Eulerian integral time scale. For large Reynold's numbers, homogeneous and isotropic turbulence and long-dispersion-time-periods experimenters have found the following empirical relationship (4,5) $\Lambda_E/\Lambda_L \approx 0.8$ Therefore, it is possible to replace Λ_E with Λ_L to obtain an approximate description of the turbulence. This has been done in meterological applications [(5) p. 34] $(\Lambda_L)_i \approx \bar{U}_1\, (\zeta_E)_i$. The Reynold's number for Nanticoke is: $R = \bar{U}D/\nu = 2.05 \times 10^5$ in which $\bar{U}$ = mean velocity, in cm per sec; D = depth in cm; and ν = kinematic viscosity, in sq cm per sec. By definition

$$\zeta = \int_0^\infty dt\, \frac{\overline{u(t')u(t'-t)}}{\overline{u'^2}} = \int_0^\infty dt\, R(t) \quad \text{(6)}$$

in which $R(t)$ = autocorrelation coefficients; ζ_E = integral of the correlation coefficients with respect to time in sec; and u = fluctuating velocity in cm per sec.

The current meter data was analyzed on an hourly basis to minimize aliasing in the energy spectra (1). Consequently, correlation coefficients were developed for hourly time lags. The question is whether hourly lags are appropriate for determining $R(t)$. Hinze (4) indicates a sampling time interval: T = length scale/mean velocity. Using the depth of 13 m: T = 7 min. On the other hand, Lumley (5) indicates a sample time interval of: $T \approx 200 \times$ integral time scale. Okubo (7) estimated the integral length scale to be approximately 2m for Lake Erie: $T \approx 200 \times$ integral length scale/mean velocity; $T \approx 200 \times 200/3 \times 60 \approx 220$ min.

As Hinze's sampling intervals are basically laboratory-oriented while

Lumley's are meteorologically-oriented, the differences are likely to be a result of the physical size of the processes. The Nanticoke characteristics would tend towards the meteorological scale. Consequently, it seems reasonable to utilize hourly lag intervals for the correlation coefficient.

As it is necessary to consider long time periods for the two-dimensional assumption, it was decided to use a month's data record in determining the dispersion characteristics. To evaluate the integral in Eq. 6 the limits must be reduced from infinity. Statistical limitations imposed by the time series analysis require that a period corresponding to 5 % to 10 % (approximately 50 hr) of the length of the data record is the maximum acceptable (1). Experience

TABLE 1.—SUMMARY OF CHARACTERISTIC DIFFUSION QUANTITIES (September, 1968)

Meter	ζ_E North, in hours	ζ_E East, in hours	Λ_L North, in centimeters	Λ_L East, in centimeters	u' North, in centimeters per second	u' East, in centimeters per second
022[a]	9.6	19.5	8.6×10^3	1.46×10^4	1.49	4.49
023[a]	7.25	9.5	3.62×10^3	4.02×10^4	0.65	3.08

TABLE 2.—FURTHER ANALYSIS OF CHARACTERISTIC DIFFUSION QUANTITIES (September, 1968)

Meter	U North, in centimeters per second	U East, in centimeters per second	Persistence factor	ϵ North, in square centimeters per second	ϵ East, in square centimeters per second
022	4.7	4.7	0.44	1.28×10^4	7.19×10^5
023	1.7	1.7	0.70	2.36×10^3	1.25×10^5

[a] For meter locations see Fig. 4.

TABLE 3.—RESULTS OF OTHER STUDIES

Reference	ϵ, in square centimeters per second
Csanady (2)	4×10^2 (one at 2×10^3)
Okubo (7)	3 to 6×10^4
Noble (6)	2.44×10^2
Palmer (8)	0.65 to 1.3×10^2

with energy spectral analyses of currents, temperatures, and water levels on the lake has shown that most major lake phenomena are included in this period. (9) These phenomena include: the wind seiche primary period of 14 hr for Lake Erie and 2.3 hr for Long Point Bay; the diurnal period of 24 hr, 12 hr and 6 hr; and the 17-hr period caused by the effects of the earth's rotation at the lake's latitude.

Velocities in the Nanticoke area were small (monthly averages for Meters 023 and 022 were 1.7 and 4.7 cm per sec respectively) with complete reversals of direction frequently occurring within 2 or 3 days [see Figs. 1 and 2, Palmer

(9)]. This is typical of near-shore areas on lakes Erie and Ontario. Consequently, it would be extremely difficult to consider dispersion for short time periods. A fundamental time period of a month permits the averaging of many reversals. Obviously, if the currents during a month were very persistent in one direction (with a persistence factor of 0.8 or greater), it would be possible to consider shorter time periods with accuracy. Persistence factor is the magnitude of the resultant current divided by the magnitude of the arithmetic mean current.

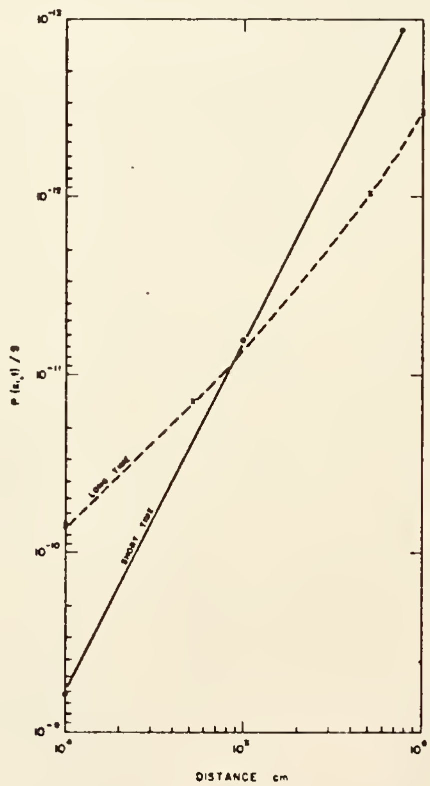

FIG. 3.—COMPARISON OF LONG AND SHORT TIME DIFFUSION PROBABILITIES

The monthly resultant current vector was used for the mean velocity $\bar{U}_i$ and the standard deviations of the monthly currents was used for estimates of the fluctuating velocities

$$u_i' = \left[\frac{(\Sigma (U_i - \bar{U}_i)^2)}{(N - 1)}\right]^{1/2}$$

The corresponding persistence factors provide an indication of the probability of the dispersion pattern occurring in the direction of the resultant current. The values thus derived are seen in Tables 1, 2, and 3.

The results compare favorably with Okubo (7) who used drogues at similar distances offshore but are significantly larger than the other studies. However, as the other studies are either surface dye dispersion determinations or evaluations in deeper water, it is felt that a comparison is not valid. A very important feature of the Nanticoke results is that they portray the near-shore processes more precisely with two-dimensional dispersion coefficients.

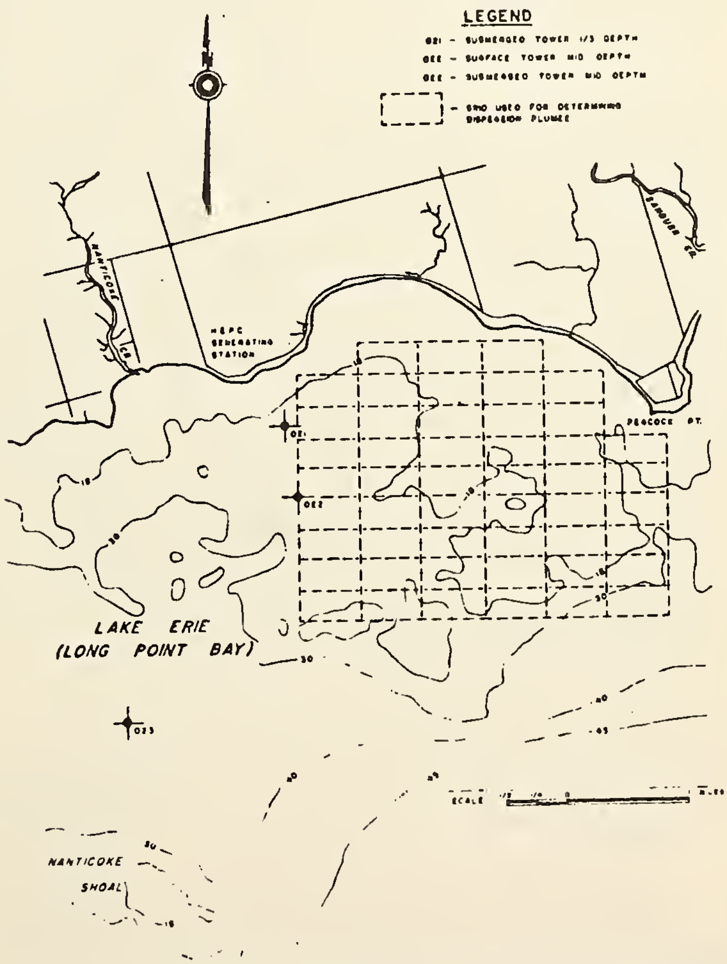

FIG. 4.—ONTARIO WATER RESOURCES COMMISSION: CURRENT METER LOCATIONS IN 1968

The dilution in September is greater nearer the shore (at Meter 022) and parallel (east) to the shore. Both the fluctuating velocities and the integral scales by the preceding method are much larger than those determined by Okubo (7) who found the fluctuating velocities to be 0.3 cm per sec and the

integral scale one to 10 m. It is certainly unlikely that the integral scale would be as small as Okubo estimates. Significant correlations exist between veloc-

TABLE 4.—SUMMARY OF CHARACTERISTIC DIFFUSION QUANTITIES
(August to November)

Month	Meter	t_E North, in hours	t_E East, in hours	Λ_L North, in centimeters	Λ_L East, in centimeters
August	022	5.98	3.86	6.75×10^3	31.2×10^5
September	022	9.60	19.5	8.6×10^3	1.46×10^4
	023	7.25	9.5	3.62×10^5	4.02×10^4
October	022	4.21	9.86	0.99×10^3	1.78×10^5
	023	17.52	25.52	7.85×10^5	3.33×10^5
November	023	13.67	28.1	1.27×10^3	4.82×10^5

The corresponding dispersion plumes are plotted in Figs. 5, 6, 7, and 8 using the source strengths (S) listed in Table 6.

TABLE 5.—FURTHER SUMMARY OF CHARACTERISTIC DIFFUSION QUANTITIES
(August to November)

u' North, in centimeters per second	u' East, in centimeters per second	U North, in centimeters per second	U East, in centimeters per second	Persistence factor	ϵ North, in square centimeters per second	ϵ East, in square centimeters per second
1.90	4.2	4.2	2.24	0.54	1.28×10^4	1.39×10^5
1.49	4.7	4.7	2.08	0.44	1.28×10^4	7.19×10^5
0.65	1.7	1.7	1.19	0.70	2.36×10^3	1.25×10^5
1.20	6.6	6.6	4.99	0.75	1.20×10^3	1.17×10^6
1.86	6.8	6.8	3.62	0.54	1.46×10^4	2.62×10^6
1.53	9.4	9.4	4.76	0.37	1.95×10^3	5.26×10^6

The corresponding dispersion plumes are plotted in Figures 5, 6, 7, and 8 using the source strengths (S) listed in Table 6.

TABLE 6.—SOURCE STRENGTHS USED IN DISPERSION PLUME COMPUTATIONS

Month	Meter	S, in square centimeters per second
August	022	5.53×10^5
September	022	5.53×10^5
	023	2.46×10^5
October	022	5.42×10^5
	023	7.76×10^5
November	023	5.45×10^5

ities at Meters 022 and 023 (Palmer (9)). The discrepancy in the fluctuating velocities is due to the different time periods considered.

The main area of concern for the dispersion plume is from 4×10^4 cm to 5×10^5 cm (1/4 miles to 3 miles) from the source. Considering that the short

time formula (Eq. 3) is limited to distances up to approximately 10^2 cm while the long time formula (Eq. 4) is limited to distances beyond 10^7 cm, the area of interest is somewhere between these limits.

The short and long time forms of Eq. 1 [(4) p. 327 and p. 329] for $x_2 = 0$ are plotted in Fig. 3. It can be seen that the area of interest is centered about the

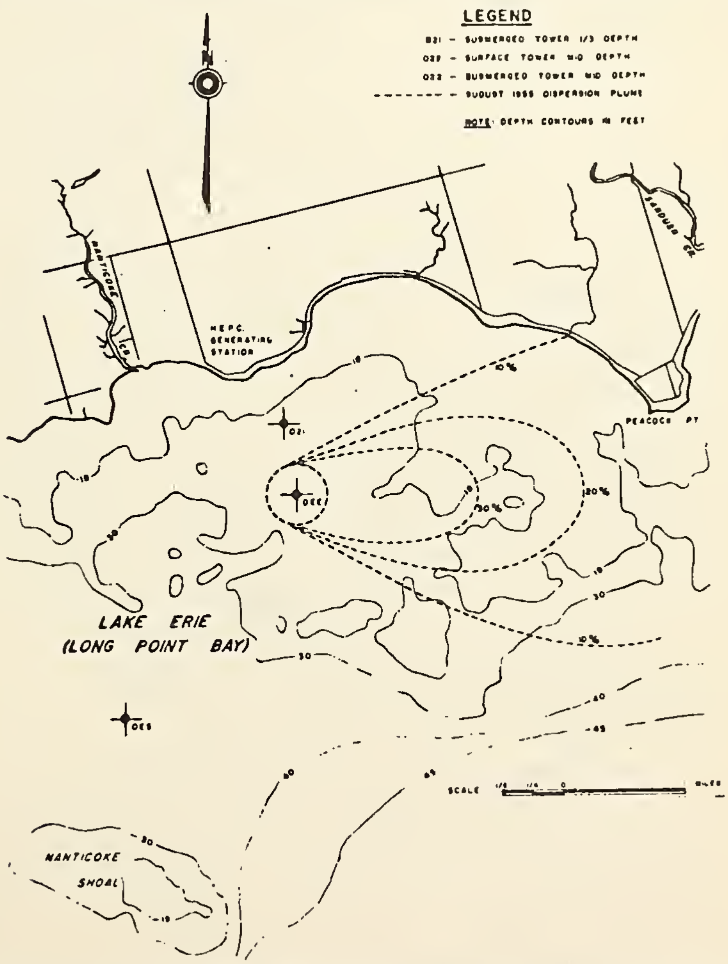

FIG. 5.—ONTARIO WATER RESOURCES COMMISSION: CONCENTRATION CONTOURS IN AUGUST

intersection of the short and long time forms of the equation. Thus, it is reasonable to use an average of the short and long time equations for this area. Short and long time equations for $\overline{y^2}$ in two dimensions (Eqs. 3 and 4) were computed for each point on a square grid (Fig. 1) and averaged. The values thus determined were then substituted into Eq. 1 which was then integrated

numerically on the computer until the last step added less than 1/2 % of the total. (The integral Eq. 1 converges rapidly with time intervals of 15 hr).

SAMPLE CALCULATION

The numerical solution of Eq. 1 generates values of P/S for various points on a two-dimensional grid (Fig. 4). For a P not greater than 1.0 at $x_1 = 4 \times 10^4$

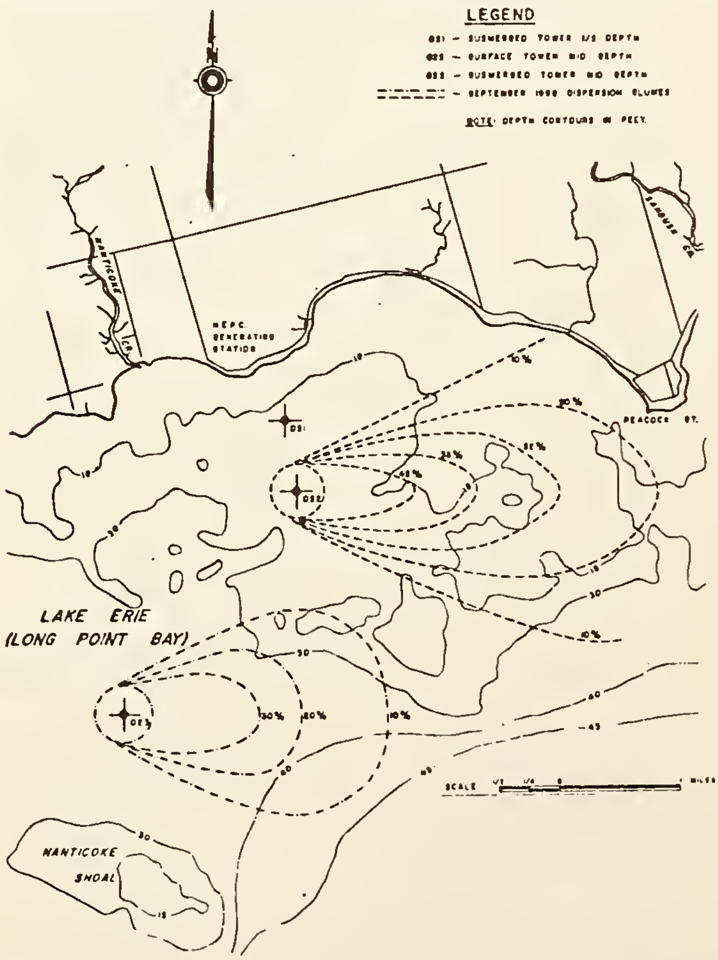

FIG. 6.—ONTARIO WATER RESOURCES COMMISSION: CONCENTRATION CONTOURS IN SEPTEMBER

cm and $x_2 = 0$, the maximum point source strength is 5.53×10^5 cm² per sec (approximately 24 cfs) for Meter 022 and "S" of 2.46×10^5 cm² per sec (ap-

proximately 10 cfs) for Meter 023. This means that for distances less than 4×10^4 cm from the source it must be assumed that a uniform concentration equivalent to source strength exists because the equations do not apply in this range. For larger flows, the area of uniform concentration would be greater. This is not unexpected as the equations reflect the fact that larger sources

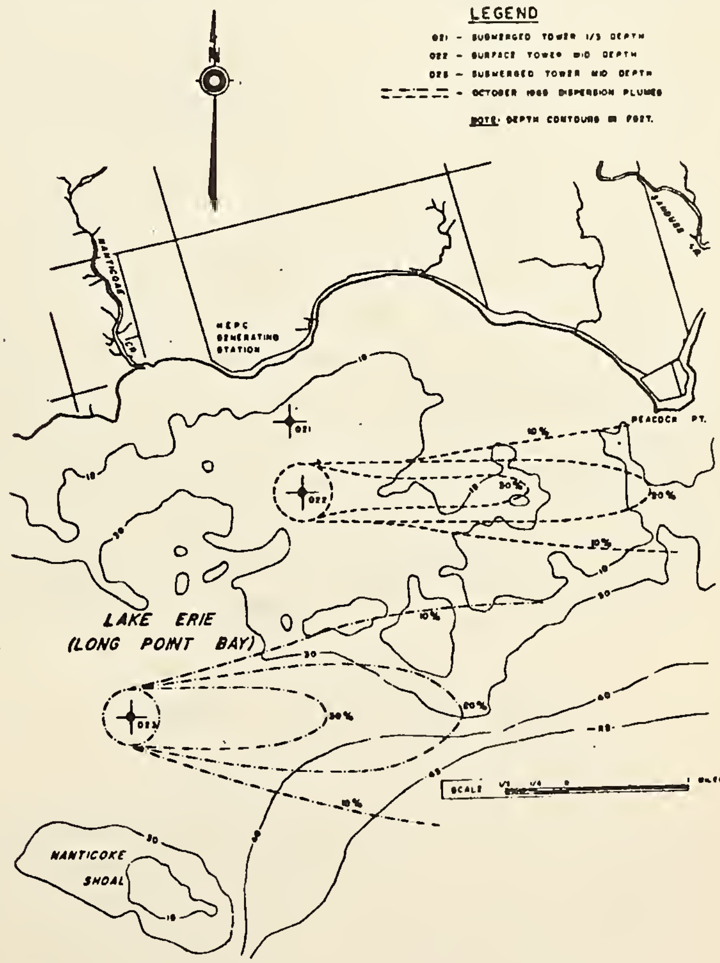

FIG. 7.—ONTARIO WATER RESOURCES COMMISSION: CONCENTRATION CONTOURS IN OCTOBER

will change the local mean velocities $\bar{U}_1$ in the immediate area to accommodate the larger flows. The mean velocities measured in this study do not apply to the larger sources. The September dispersion plumes for a source strength $S = 5.35 \times 10^5$ sq cm per sec and $S = 2.46 \times 10^5$ sq cm per sec at Meters 022, and 023, respectively, are plotted in Fig. 6 as percentages of the source

strength. This means that if the source strength is 10 ppm, the concentration on the 50 % contour would be 5 ppm.

RESULTS

The results for the meters in August, October and November are tabulated in Tables 4, 5, and 6. The diffusion coefficients for November compare favor-

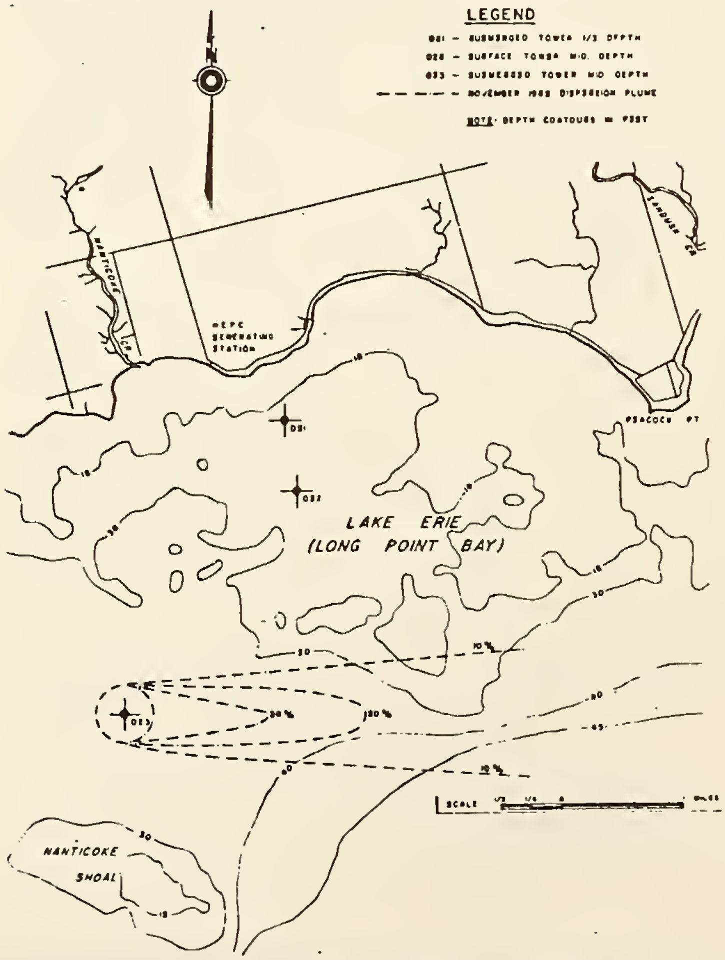

FIG. 8.—ONTARIO WATER RESOURCES COMMISSION: CONCENTRATION CONTOURS IN NOVEMBER

ably with results obtained by a conventional drogue study carried out at the same time and location but farther offshore (3). Meter 023 was not installed until September and there were only 10 days of good data for Meter 022 in

November. Consequently, the record is too short to produce reliable results and these values have been omitted.

CONCLUSIONS

The preceding method for predicting the monthly dispersion plumes for a continuous point source provides a comprehensive portrayal of the nearshore processes. It permits differentation of the dispersion characteristics in two-dimensions for various locations offshore. By using the continuous records from current meters, the method considers the time-dependent and periodic nature of the currents serially. The periodic nature of the current regime necessitates the development of average conditions over reasonable time periods. Consequently, the resulting plumes (Figs. 5, 6, 7, and 8) do not represent the dispersion at any particular time, but are the average of conditions occurring throughout the month. The method also predicts how far a new source will alter the current patterns in the area.

The method is based upon information obtained from a fixed recording two-dimensional current meter. It is necessary to assume that the Eulerian integral length scale is approximately equal to the Lagrangian integral length scale to determine the dispersion characteristics. This restricts the application of the method to large Reynold's numbers, diffusion over long periods of time and homogeneous and isotropic turbulence. The development of concentration contours requires the concurrent operation of other meters in the area to define areas of similar water movement characteristics. The November diffusion coefficients obtained by this method compare favorably with results obtained independently with drogue studies conducted by the Canada Centre for Inland Waters, Burlington (3).

APPENDIX I.—DIFFUSION COMMENTS

The second assumption that the diffusion coefficients are reasonably constant over a region of the lake based upon cross-correlations between two current meters still seems a valid assumption. It is agreed that the diffusion coefficient is related to the gradient of velocity and not the absolute value. However, the time-series comparison of hourly velocity readings for a month from two different meters indicates that the two points are in the same flow regime and water movements at the two points are related. Therefore, the diffusion coefficients at the two points are assumed similar.

Tables 4 and 5 extend the results of Tables 1 and 2 to include the months of August, October and November. Consequently, Tables 4 and 5 provide information on seasonal variations.

Temperature measurements are not referred to in the paper; therefore, no reference is made to stratification. The area of the study is a large (8 km by 5 km area) bay where the maximum depth is 14m and temperature measurements indicate only small thermal stratification or isothermal conditions.

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APPENDIX III.—NOTATION

The following symbols are used in this paper:

D = depth;
$P(x_1, x_2)$ = probability of finding a marked fluid particle at x_1, x_2;
R = Reynold's number;
$R(t)$ = autocorrelation coefficient;
S = continuous point source;
T = sampling time interval;
t = time;
$\bar{U}_1$ = mean velocity (east-west);
u = fluctuating velocity;
u' = root mean square fluctuating velocity;
x_1, x_2, x_3 = coordinate directions;
$\overline{y_1^2}$ = variance of the displacement in east-west direction;
$\overline{y_2^2}$ = variance of the displacement in north-south direction;
ϵ = one-dimensional diffusion coefficient;
ϵ_{ij} = diffusion coefficient tensor of second order;
ζ_E = Eulerian integral time scale;
ζ_L = Lagrangian integral time scale;
Λ_L = Lagrangian integral space scale;
Λ_E = Eulerian integral space scale;
ν = kinematic viscosity;
π = 3.141593; and
τ = time.

7464 DISPERSION PREDICTION FROM CURRENT METERS

KEY WORDS: autocorrelation; current meters; diffusion; dispersion; hydraulics; shores; turbulence

ABSTRACT: Two-dimensional dispersion plumes for the near shore area of Nanticoke on Lake Erie are predicted by applying turbulent diffusion concepts to recording current meter data. Eulerian integral time scales are found from autocorrelation coefficients, based on monthly data. Lagrangian integral space scales and one-dimensional diffusion coefficients are then predicted. Average monthly probability distributions are found based on north-south and east-west diffusion coefficients. The prediction equation is an average of long and short time diffusion equations. The results show better dilution nearer the shore and parallel to it. It has been assumed that vertical diffusion is negligible, that the Reynold's number is large, and that the effective diffusion coefficients are constant over long periods.

REFERENCE: Palmer, Mervyn D., and Izatt, J. Bryan, "Dispersion Prediction from Current Meters," Journal of the Hydraulics Division, ASCE, Vol. 96, No. HY8, Proc. Paper 7464, August, 1970, pp. 1667-1680.

APPENDIX II

AN EVALUATION OF THE RICHARDSON CURRENT METER SYSTEM

by

Paul Ferris Smith, Staff Oceanographer
Geodyne Division/EG&G International

After seven years of intensive use, it seems appropriate to take this opportunity of the 1968 Marine Technology Society's Instrumentation Committee's Symposium on Current Instruments and Techniques to evaluate the Richardson Current Meter System. The first large scale use of this system was begun in the spring of 1961 under the direction of Dr. William S. Richardson, its originator, while on the scientific staff of the Woods Hole Oceanographic Institution (Richardson, 1962 and Richardson, et al 1963). Since that time, the use of this system has grown and been employed extensively throughout the world to acquire a vast quantity of new direct measurements of ocean, estuarine, and lake currents. During this period the fundamental principles underlying this system have remained unaltered while at the same time numerous elaborations and variations on these principles have been developed. These changes have been aimed at both increasing the overall reliability of this system and the overall flexibility and convenience of it in use.

While the system itself will be discussed in some detail below, the most obvious component of this system is the current meter itself. This was first designated the Woods Hole Richardson Current Meter Model A-100 and Figure 1 shows one of these being lowered over the stern of the Woods Hole Oceanographic Institution Research Vessel CHAIN in October 1962. Dr. Richardson is seen partially obscured assisting in this operation. Since that date, other models meeting particular service requirements or having special features have been developed. These include the USNOO version, Model 101; the single-ended sensor version Model 102; the telemetering version first supplied to the Bell Telephone Laboratories and later developed into ESSA'S TICUS System for the U. S. Coast and Geodetic Survey; the inductively coupled version; and the most recent version the Model 850 Tape Recording Current Meter (the original current meters were digital film recording). In the near future (early 1969) there will be yet another version, also tape recording, but with the added capability of recording other variables than current such as temperature, depth, and conductivity. All of these versions of the Richardson Current Meter employ the standard Savonius Rotor to sense current speed and the same vane-compass combination to sense direction. All sample these sensors at a high rate to prevent aliasing and all obtain the variables in a standard format suitable for automatic processing. These instruments have been fully reported in the literature and the list of appropriate references is included as Appendix A. These references include not

only descriptions of the various current meters and descriptions of the developments to improve reliability and performance and simplify its use, but also discussions of the problems and solutions associated with the automatic processing of recorded or telemetered data. As the systems discussion below will show, this step is an essential aspect of the Richardson Current Meter System(Smith, 1963).

A current measuring system addresses itself to the one problem illustrated in Figure 2. This is the problem of obtaining from a data source outputs which are of value to science and technology. To be effective, such a system must make this link without a bottleneck diagrammatically suggested by this figure. The Richardson Current Meters system's effectiveness in providing this link can be measured, in part at least, by the sheer quantity of data which has been obtained using it. In Appendix B there is a list of published papers and reports utilizing this data and while this is not a complete list, the attempt has been to include examples from the principle users and from as diverse applications as possible. This list in itself is impressive, containing as it does thirty-one titles; a few statistics are also. Geodyne, for example, has read and processed data from 2,250 films. Telemetering and tape recording instruments are generally read and processed by the instrument users themselves so while this represents a major fraction of the recorded data, it is far from all. These films have come from such institutions as the U. S. Naval Oceanographic Office, the U. S. Coast and Geodetic Survey, the U. S. Public Health Service, the Bureau of Commercial Fisheries, the U. S. Navy Civil Engineering Laboratory, the U. S. Navy Mine Defense Laboratory, Scripps Institution of Oceanography, Hudson Laboratories, Narragansett Marine Laboratory, Massachusetts Institute of Technology, and the Woods Hole Oceanographic Institution, as well as from commercial organizations such as General Motors Defense Lab, Alpine Geophysical and Ocean Science & Engineering. Data has been obtained not only from the United States but also from Germany, France, Sweden, Japan, Canada, Argentine, and Venezuela. One particular oceanographic laboratory, quite naturally the institution where the system was first evolved, has obtained an enormous amount of data. This is the Woods Hole Oceanographic Institution whose three volumes (Webster and Fofonoff 1965, 1966, and 1967) summarize the data from 53 records obtained from 18 stations during the years 1963 through 1964. From the years 1965 to 1967, an additional 1,762 data days have been recorded amounting to over 5 million more current vectors! All of this data is useable data from which questionable records due to instrumentation malfunction or other causes have been excluded. But the real question is not how many current vectors have been obtained but what has been learned about the circulation of the ocean and about the instrumentation system which will further its understanding.

Briefly, what has been learned supports the viewpoint which in part lead to the development of the current meter system in the first place. This view had its origin in 1960 when Henry Stommel, aboard the Research Vessel ARIES with the aid of John Swallow and his Swallow Floats, observed currents in the deep ocean at 2,000 and 4,000 meters far in excess of those predicted by geostrophic considerations. These currents measured from 6 to 13 cm/sec, an order of magnitude higher than expected, and in addition exhibited substantial very low frequency time variability of the order of one or two months. These findings indicated that a statistical mean value could not be obtained practically using this technique. The Richardson Current Meter System evolved soon thereafter in response to this and other needs. Stommel mentioned these findings in his opening lectures to the Geophysical Fluid Dynamics Course at the Woods Hole Oceanographic Institution this summer (1968) and then went on to say that abyssal circulation is still not clearly delineated. The results to date from direct current measurements with the Richardson System clearly demonstrate that describing this circulation is a very tough oceanographic problem. The scales of motion are exceedingly complex and the bandwidth of signals which must be dealt with extremely wide. As Richardson said in his first article on current measurements from moored buoys (Richardson, 1961) "Deep currents are swifter and more variable than had been expected". Consequently, he concluded, it was necessary to design a direct current observation system" to obtainlonger time series of current measurements over more extended areas". Furthermore, recognizing the potentially large data reduction problems presented by this number of measurements, he designed his system to be compatible with automatic computer data processing. Data from some of the papers listed in Appendix B will amply demonstrate the validity of this observation and of this approach. Examples from a few of these will be presented and discussed below.

But first it should be pointed out that the purpose of all current measurements is not the scientific study of circulation. Many current measurements are intended for engineering uses to support certain oceanic operations such as undersea warfare, and water pollution problems including the design water supply systems, power plant cooling systems, and the disposal of sewage and waste. In each of these, however, meaningful valid current measurements must be obtained and it is clearly obvious that this places exactly the same requirement on the current measuring system as does the research function. These too are tough problems. For this reason and for the sake of brevity, the present evaluation of the Richardson Current Meter System will make reference solely to the results of scientific studies.

As a starting point in this evaluation, I have selected Figure 1 from Webster's paper "A Scheme for Sampling Deep-Sea Currents from Moored Buoys" (Webster, 1967), see Figure 3. This Figure is a power spectrum showing

the kinetic energy to which a moored current meter is subjected by both the oceanic current structure and the current and wave induced mooring perturbations. Since, as Von Arx has pointed out (Von Arx, 1962, pg 213), it is essential to obtain direct current measurements relative to a frame of reference at rest with respect to the earth and further since this is as yet impractical, the high frequency signals present from the non-stationery characteristics of the instrument mounting, i.e. the mooring, must be considered in the current measuring system design. As can be seen in Figure 3, this is a six-decade spectrum of wide amplitude variations and as such represents a considerable challenge to the design of a current measuring technique. Where only the low frequency components are of scientific interest, a sampling scheme must be chosen to accommodate the presence of the high frequency signals and Webster's paper from which this spectrum was taken clearly demonstrates that this is possible with this instrument. He discussed the complexity of the problem earlier (Webster, 1964b). In his paper, "On the Representativeness of Direct Deep Sea Current Measurements" (Webster, 1968a), the results of an analysis of some of the resulting data is presented. Several illustrations have been chosen here from this paper too. All of these clearly show why it must be said that the circulation is not yet clearly delineated and all of these equally clearly demonstrate the need for a more extensive use of a system capable of collecting and analyzing the enormous amounts of data required by so complex a problem. Take, for example, Figure 4 which is taken from Figure 3 in the above paper. This is a progressive vector diagram (for an explanation of this computer generated presentation see Webster's paper "Processing Moored Current Meter Data", Webster, 1964a) obtained from a recording made by an instrument at a depth of 120 meters located at 30°20' North and 70° West in the North Atlantic. This location is designated by Woods Hole Oceanographic Institution as Site D. This recording extended from 24 June 1965 to 11 August 1965 and clearly not one segment, even though it may last as long as two weeks, could be described as typical of the currents at this station during this period. Reference to Webster's paper is necessary for a full discussion of this data, however, Figure 5, taken from his Figure 2 (Ibid), dramatically demonstrates the changing character of ocean circulation. This is an enlargement of a section of the progressive vector diagram of the previous figure for the ten day period 8 July to 18 July 1965. Here the motion is clearly dominated by a semi-diurnal rotary tidal current of a period of about 12 hours which is in striking contrast of the other portions of the record. Another progressive vector diagram, Figure 6, also taken from data recorded at Site D, depth 522 meters, 25 June 1965 to 15 August 1965 provides further proof of this bewildering complexity. This illustration was taken from Figure 9 of the same paper as the first two. On it there is an enlarged portion which again shows rotary motions dominating the current. But now these have a period of 19 hours corresponding to inertial motions at the Side D latitude which are not present in other portions of the recording! This variability of the inertial term in the current signal is clearly seen in another illustration taken from Webster's article in the Review

of Geophysics entitled: "Observations of Inertial Period Motions in the Deep Sea" (Webster, 1968b),Figure 5. This computer generated graphical presentation, here Figure 7, shows the North and East components of velocity as a function of time from a current meter at seven meters depth at Site D. The large amplitude oscillations have inertial periods. They clearly build up and die out frequently during the recording period from 5 October 1965 to 20 November 1965.

Understandability is emerging out of this complexity, however. From four recent records at Site D there is striking evidence of coherence between the data from the three lowest instruments located at depths of 510 m, 1013 m, and 2020 m. The progressive vectors from these have uniquely similar appearances having, in general, decreasing velocity magnitudes with increasing depth. The progressive vector from the near surface record, at 106 m, is wholly dissimilar as might be expected since it is in the mixed layer. This data will be presented and its relation to such other factors as turbulance and internal waves discussed in forthcoming papers from Woods Hole. Clearly this is most encouraging data for the understanding of the processes of oceanic water movements.

While it is apparent from the above that the dilineation of ocean circulation is a tough problem, the Richardson Current Meter System is one which appears equal to the task. Simply stated the advantage of the Richardson Current Meter System is that it handles the data in digital form. This is what enables it to acquire data accurately and process it easily. There are other advantages to this digital approach. Analog data cannot be telemetered to a sattelite, for example. And when the independent variable needs to be known as accurately as the dependent variable, a digital time number can be recorded along with the current measurements. There are disadvantages too, to the Richardson Current Meter System. Similarly simply stated these are to be found in the fragility of the delicate sensors: the rotor, the vane follower, and the compass. Except for mooring failures, malfunction of these sensors has been the major cause of difficulty with the system, but this sensitivity is required by the bandwidth and the dynamic range of the signals which must be dealt with (see Figure 3). Design improvements aimed at reliability assurance together with quality control acceptance test procedures have substantially reduced these difficulties.

Figure 8 illustrates diagrammatically the components of a current meter system. As shown from left to right they consist of the sensors, the storage unit, the interface to the computer, and the computer itself. In view of the nature of the measuring problem there are certain constraints which must be met by these components. What these are and that they are met by the Richardson Current Meter System follows.

First the sensors: The sensor characteristics must be understood and their response to the six decades of signal input also understood so they can be employed to give meaningful unambiguous information. It is not sufficient that the sensors are known to respond to currents! The Savonius Rotor, the current speed sensor in the Richardson System, is undoubtedly the most thoroughly studied current sensor yet devised (Gaul, 1963; Hankins, 1963; Richardson et al, 1963; Sexton, 1964; Goss and Knox, 1965; Fofonoff and Ercan, 1967.) The most recent of these studies included also an investigation of the vane sensor characteristics which, following the original design studies of Richardson, had also been investigated by John Garrett at WHOI (personal communication). Furthermore the study of Fofonoff and Ercan definitely established the symmetrical characteristic of the Savonius Rotor response to increasing and decreasing speed changes thereby answering one extremely persistent and important question. In addition to these investigations of the sensors themselves, the dynamics of the current meter have also been the subject of an exhaustive theoretical analysis (Froidevaux, 1968). This analysis was based upon a series of emperical measurements of the instrument dynamics in the real ocean environment conducted by the MIT Instrumentation Laboratory employing rate gyros and accelerometers (Toth and Vachon, 1968).*

Second, the storage: The storage capability of the instrument must be very large. It is. In both the film version and the magnetic tape version, for example, a complete vector may be recorded at 5 second intervals continuously for well over one week. Suitably spaced (15 min) bursts of 24 samples giving meaningful vector averages provide for 2 months of recording. This is one of a number of alternates available in the interval mode of operation which can provide up to one year of recording. The total number of recorded vectors per instrument per installation is over 150,000. Telemetering instruments are, of course, not limited to any set amount of data as are self-contained recording instruments.

Third, the interface: The interface must be efficient and capable of handling a vast quantity of data rapidly and in such a way that the computer can operate on it efficiently. In the Richardson System, one complete film record can be transferred to IBM tape (computer compatible) in about one hour and a complete magnetic tape record in much less time.

And finally, the computer: Once the data is in IBM format there is no limit to the amount which can be done with it on a suitably programmed computer and tne time required is a function only of the program complexity and the computer capability. It should also be noted that tape and telemetering instruments may omit the tape transfer step for the data can be accepted directly in real time or on playback by a computer through an interface unit. This is practical with small computers and is employed aboard ship for rapid data analysis while on station as well as in the laboratory or shore station. The information output formats from computers suitable for scientific or engineering use of the current data are almost limitless. Programs exist (Webster, 1964; Smith, et al, 1964) for listing the complete set of measurements, for generating vector averages, for producing the progressive vector

*See also "Note" under References

diagrams and the time dependence graphs of the North and East Components discussed above, for generating histograms and speed direction scatter plots, for speed and direction graphs as a function of time, etc. etc. And there will be many more such programs.

As can be seen from the above, the significant factor in the Richardson Current Meter System is that there are no bottlenecks between the data sources and the information presentation. There is no necessity for any slow tedious manual manipulation such as the operation of a key punch. This system is designed in wholly modern terms. It is not only that the current meter itself can record a lot of data for a long time. In fact a torpedo-shaped propeller-driven 400 day recording current meter was developed at the Woods Hole Oceanographic Institution 1/4 of a century ago. It photographed a compass and a counter but to the best of my knowledge, no useful data was obtained with this instrument. Processing the information was just too cumbersome (personal observation). Well before this, even in the last century as the Monaco Museum exhibits show, and after, numerous other current meters have been designed. They responded to currents for as Von Arx so clearly put it "The procedures that have been tried or used to measure the motions of sea water are so numerous that they nearly exhaust the roster of physical possibilities" (Von Arx, 1962, pg. 214, see also Horrer, 1967). The question that must be asked of these is, are they commensurate with the large scale nature of the problem? If they are not compatible with automatic data reduction they are probably not for the power of modern computers holds out the most hope for understanding ocean circulation and the circulation within other bodies of water. That this is the case and also that the emensity of the task is well recognized by those charged with creating national policy and programs for the study of water mass properties is obvious. See, for example, the Travelers Research Center report on the Feasibility of National Data Buoy System to the U. S. Coast Guard (Aubert, 1967.) In the case of the Richardson Current Meter System, each component shown in Figure 8 has been designed with the magnitude and the technical complexity of the problem in mind and while each has undergone substantial evolution the original principle of a high-capacity, wide bandwidth, accurate system has been maintained during its use the past seven years with impressive effectiveness.

Figure 1.- A Richardson Current Meter Being Lowered Over the Stern of the WHOI Vessel R/V CHAIN, October 1962.

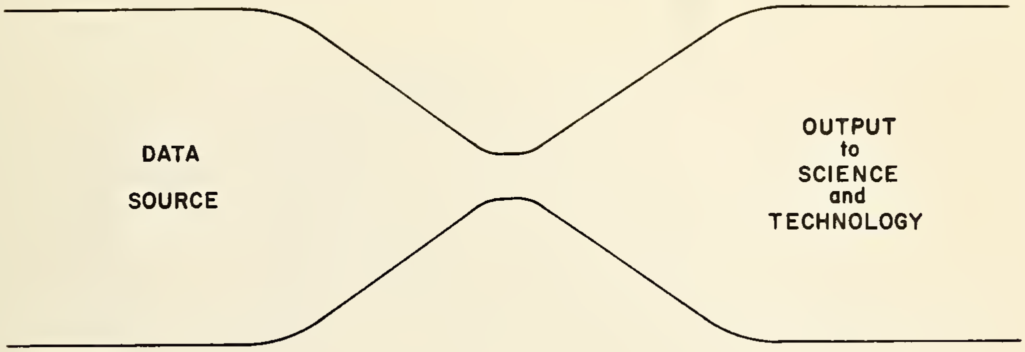

Figure 2. A Current Measuring System - The Problem.

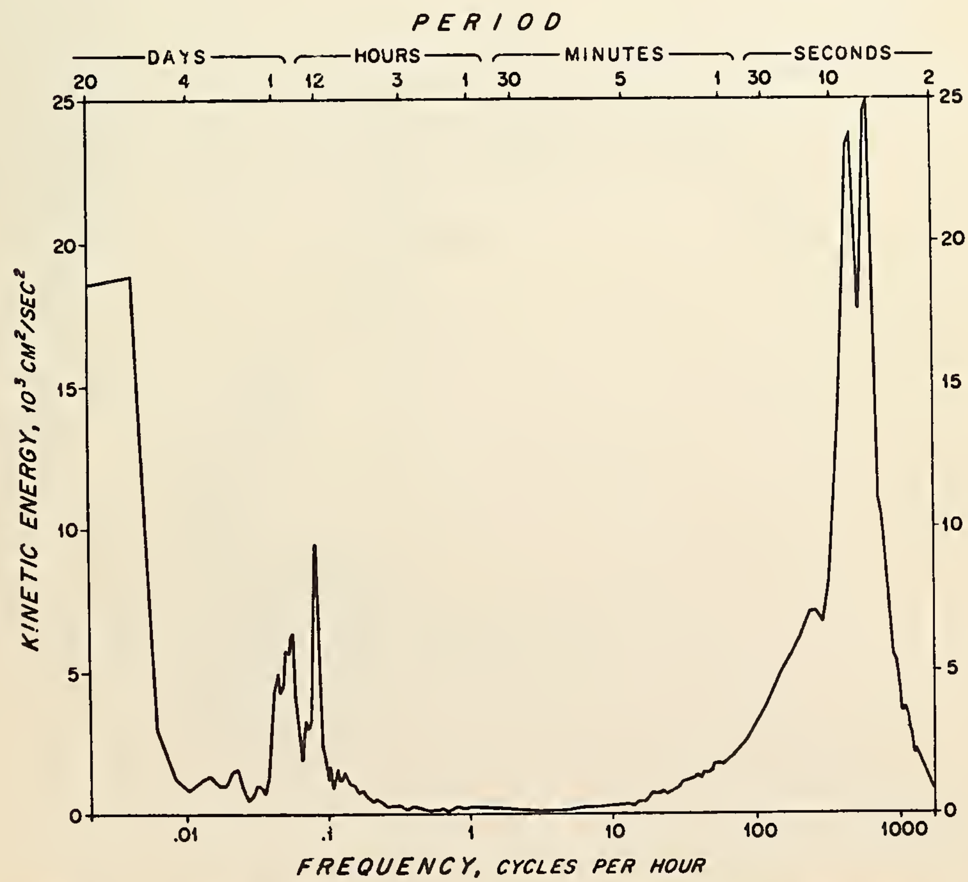

Figure 3. A Kinetic Energy Spectrum to which a moored ocean Current Meter is subjected (Webster, 1967)

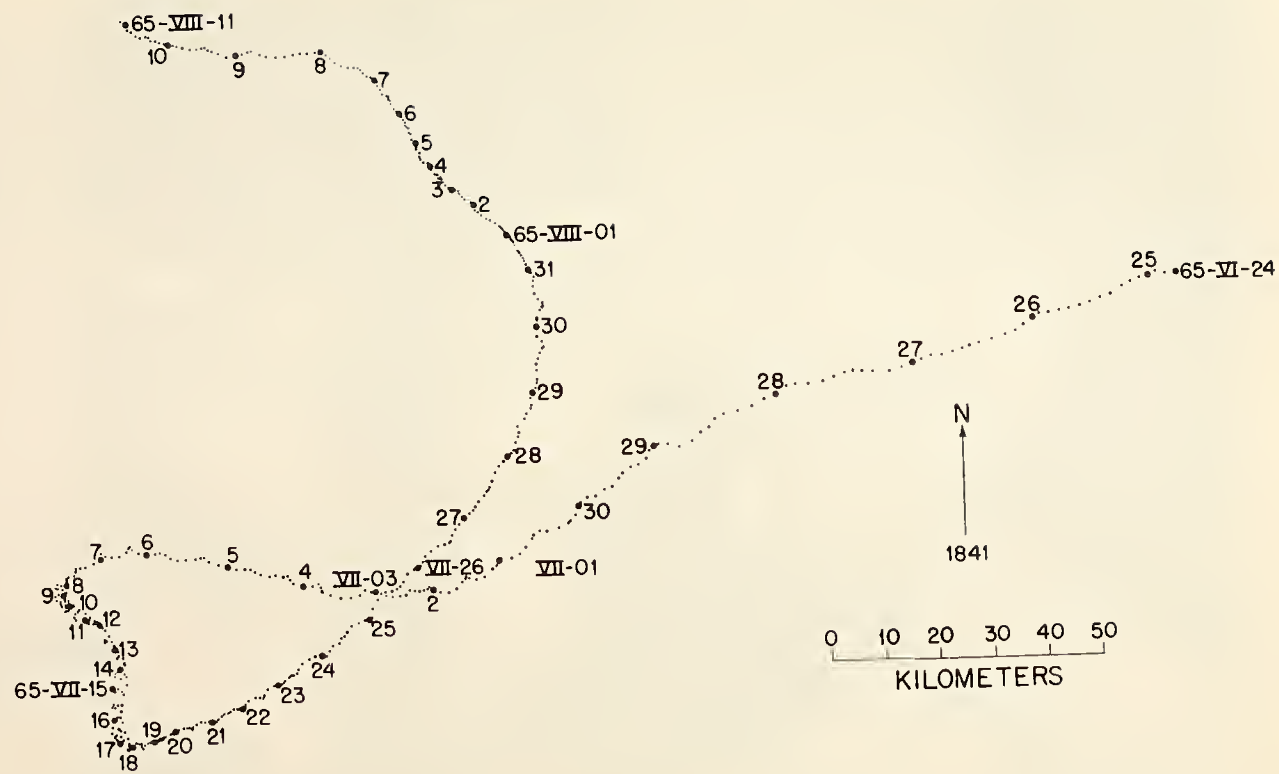

Figure 4. A Progressive Vector Diagram prepared by the Woods Hole Oceanographic Institution using a Richardson Current Meter System. Data recorded 24 June 1965 to 11 August 1965, Site D, Depth 120 m. (Webster 1968).

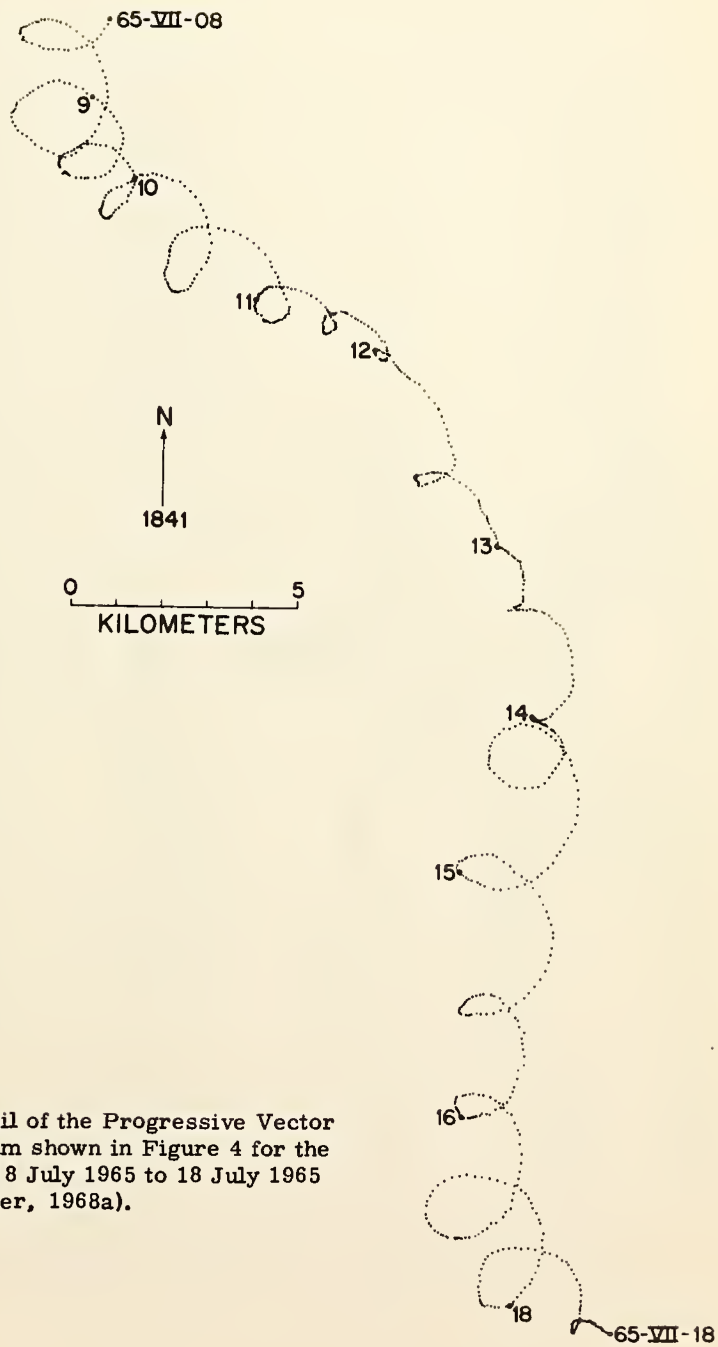

Figure 5. A Detail of the Progressive Vector Diagram shown in Figure 4 for the period 8 July 1965 to 18 July 1965 (Webster, 1968a).

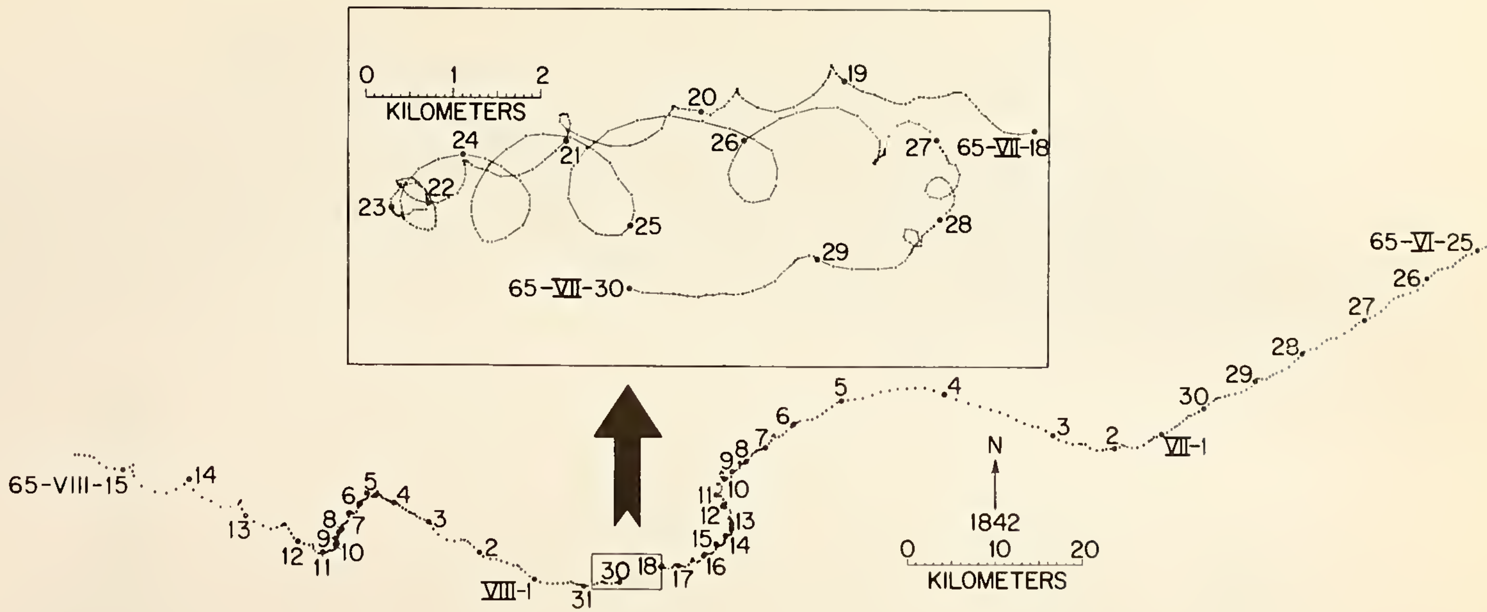

Figure 6. A Progressive Vector Diagram prepared by the Woods Hole Oceanographic Institution using the Richardson Current Meter System. Data recorded 25 June 1965 to 15 August 1965, Site D, Depth 522 m. (Webster 1968a).

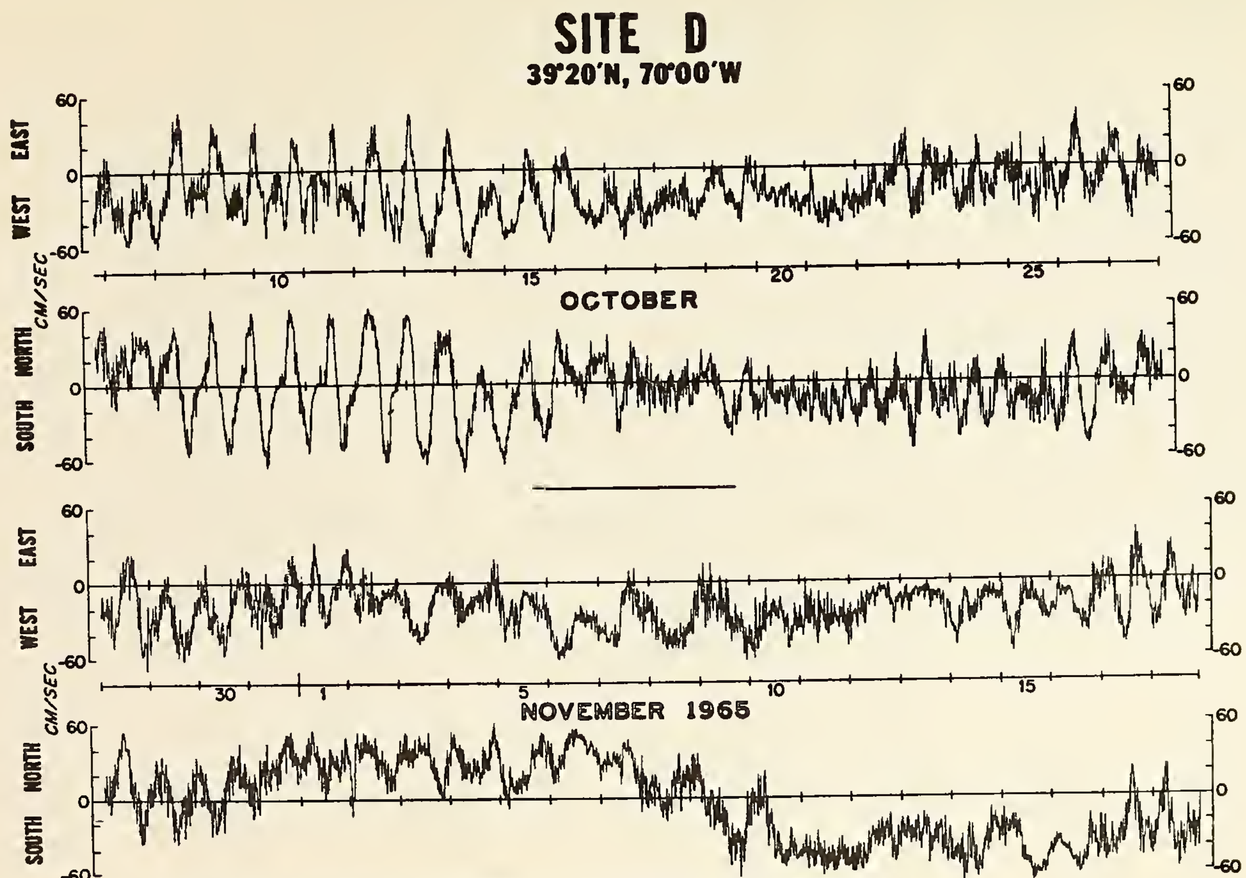

Figure 7. North and East Components of Velocity as a Function of Time prepared by the Woods Hole Oceanographic Institution using the Richardson Current Meter System. Data recorded 5 October 1965 to 20 November 1965, Site D, Depth 7 m (Webster 1968b).

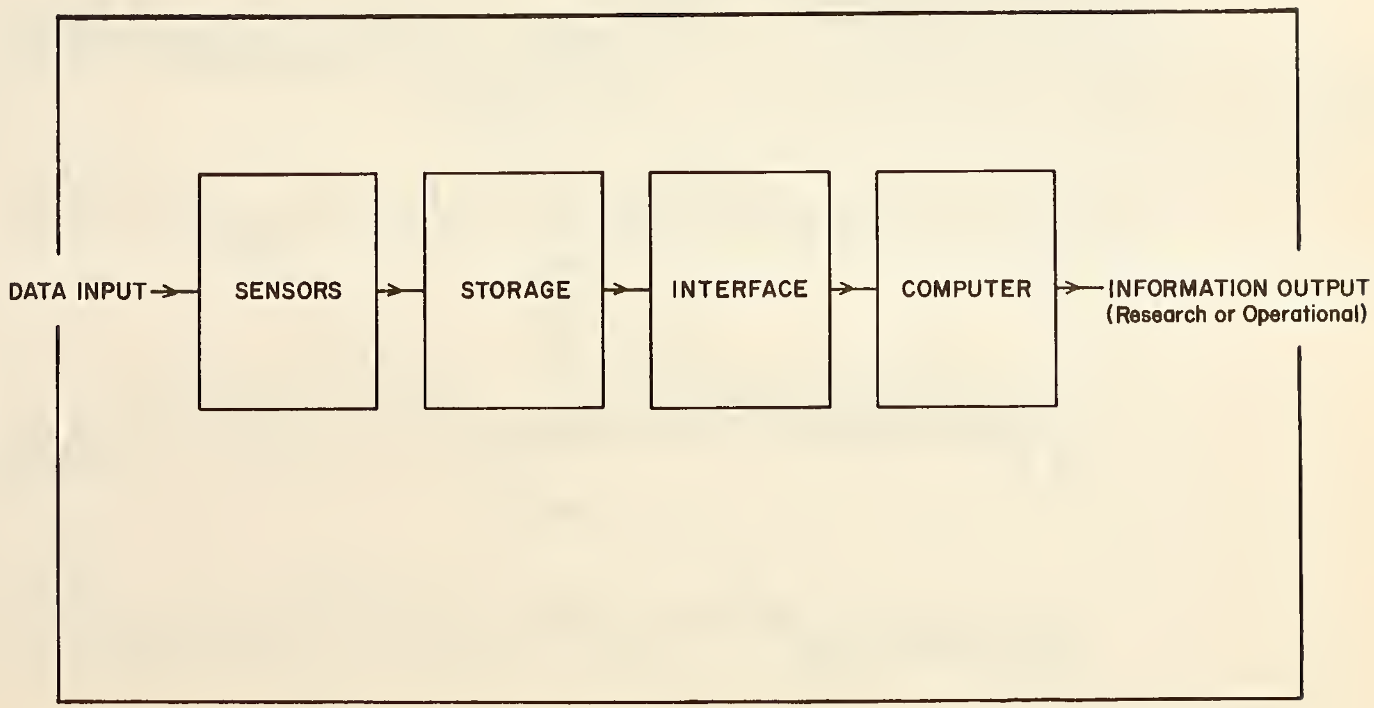

Figure 8. The Components of a Current Measuring System.

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GEODYNE® MODELS 102 & 850 CURRENT METERS

EG&G digital recording current meters sense ocean and fresh water current speed and direction and automatically record data on either photographic film or magnetic tape. They are in use in more than twenty countries in scientific and military oceanography, ocean and estuarine current surveys, thermal pollution studies, offshore structural engineering studies and a variety of other projects.

EG&G Current Meters are designed for use in moored or bottom mounted applications in shallow or deep water (up to 17,000 ft). Battery and recording capacities allow data gathering for periods in excess of a year with a single implantment. Digital techniques are the indicated choice for accurate measurement of current speed and direction versus time, for automatic processing of this data in a wide variety of output formats and for rapid sampling to detect high frequency changes.

Two digital recording current meters, the film recording Model 102 and the tape recording Model 850, enable the user to generate digital recordings of highly accurate current speed and direction. These recordings can be inexpensively processed in a variety of useful ways by EG&G's data processing service or by the user's own digital computing facility. Both current meters employ a Savonious rotor as speed sensors, widely accepted as the standard sensor for current measurements, and a balanced vane mounted adjacent to the rotor. The vane, together with the internal compass, is the direction sensor.

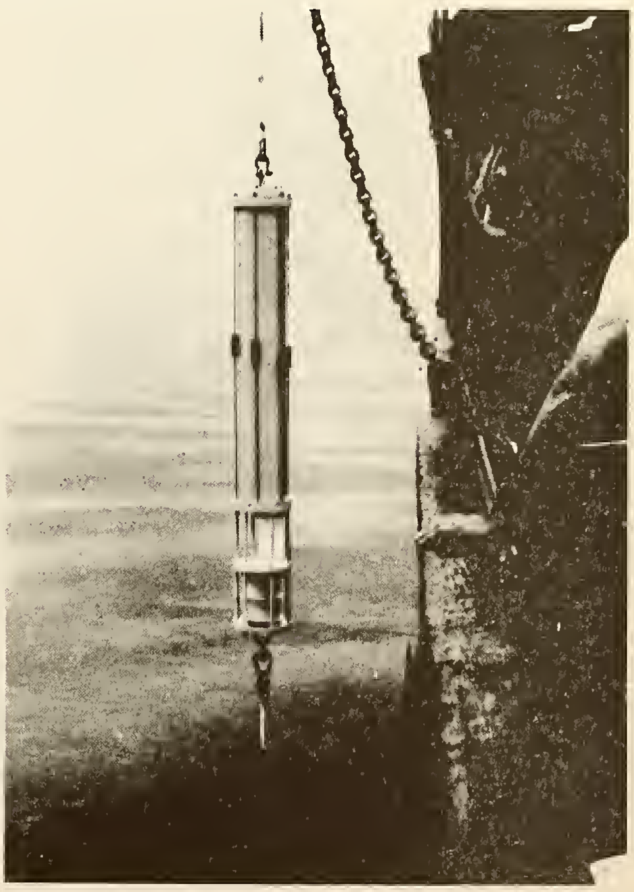
Size, weight and performance specifications for Model 102 and Model 850 are similar except for data capacity and data recording method. Application determines the choice between them:

Model 102 – Reliable, low cost, simple data format. Preferred for survey and short to medium term installation.

Model 850 – High data recording capacity and recording flexibility compatible for computer processing. Recommended for scientific and research installations, especially for long in situ periods.

Model 102 Current Meters record on 16mm film. Although the user can develop the exposed film and manually "read" it, most users simply forward the film to EG&G where it is processed. The (user's) choice of computer plots is generated and returned. This process enables users to generate large amounts of accurate data without the expense of in-house data processing and reduction facilities.

Model 850 Current Meters record digital data serially on 1/4 inch magnetic tape. Serial recording is used to avoid recording head skew problems and the subsequent difficulties experienced in data processing. Magnetic tape recording offers the user several advantages over film. Tape allows an 80% increase in data capacity and can be processed readily by users who have computer services available. Completed tapes may be played back at sea using EG&G's Digital-to-Analog Converter, tape recorder and appropriate strip chart recorder for display. For computer processing, EG&G tape-to-tape converter can convert the serial tape to a seven track IBM compatible tape. EG&G also provides processing service for these magnetic tapes and offers the same wide choice of graphic plots as available with the Model 102 Current Meter films.



DESIGN

As indicated above, current speed is sensed by a Savonius rotor. The rotor is designed to provide a low starting threshold. The Savonius design has been extensively researched and its characteristics are better understood than any other current sensor. The sensor rotations are magnetically detected, and the revolutions counted on an electronic digital counter.

Relative current direction is sensed by a hydrodynamically stable, balanced vane. The vane direction is magnetically coupled through the pressure housing to an encoder disc to provide angular position information. Compass information (for direction reference) is also supplied by a similar encoder coupled to the earth's magnetic field. Output from each of these encoders is a seven bit Gray binary coded digital number.

RELIABILITY

EG&G has manufactured well over 1,000 digital film recording current meters. To meet the demand for increased recording capacity and accuracy, EG&G had developed and delivered large quantities of the Model 850 magnetic tape recorder current meter, which utilizes advanced digital techniques.

Under the guidance of EG&G's Quality Assurance Department, continuous testing programs are run to determine areas of product reliability improvement. Such tests include life, power consumption, sensor accuracy, corrosion and fouling, temperature shock and mechanical function. These programs assure the user of EG&G's high standards of quality and reliability.

RECORDING CAPACITY

Data from the sensors is strobed at a 5 second rate and may be recorded continuously or samples may be taken at various intervals, depending on the purpose of the measurements. Sample interval length is controlled by the choice of several timing cams provided with the current meters which permit interval choices of 5, 10, 15, 20, 30, or 60 minutes.

In the Model 850, during each sample interval, recording durations of 40, 80 and 160 seconds may be selected by a switch. Choice of recording duration is dictated by the specific requirements of the measurements. The Model 102 has a fixed recording duration of each recording interval of one minute, during which a single data block is recorded.

cording interval of one minute, during which a single data block is recorded.

The maximum number of recording days available in the Model 850 is calculated by the formula:

$$\text{Recording Days} = \frac{520 \times \text{Sampling Interval (min.)}}{\text{Recording Duration (sec)}}$$

In the case of continuous recording, 8-3/4 days of recording is available.

The Model 102-0 has a fixed recording duration of 60 seconds, so sampling rate alone determines the number of available recording days according to the formula:

$$\text{Recording Days} = 6.9 \times \text{Sampling Interval (min.)}$$

In the Model 102-1, the constant in the above formula becomes 3.45.

In the case of continuous recording, the Model 102 provides 7 days of recording.

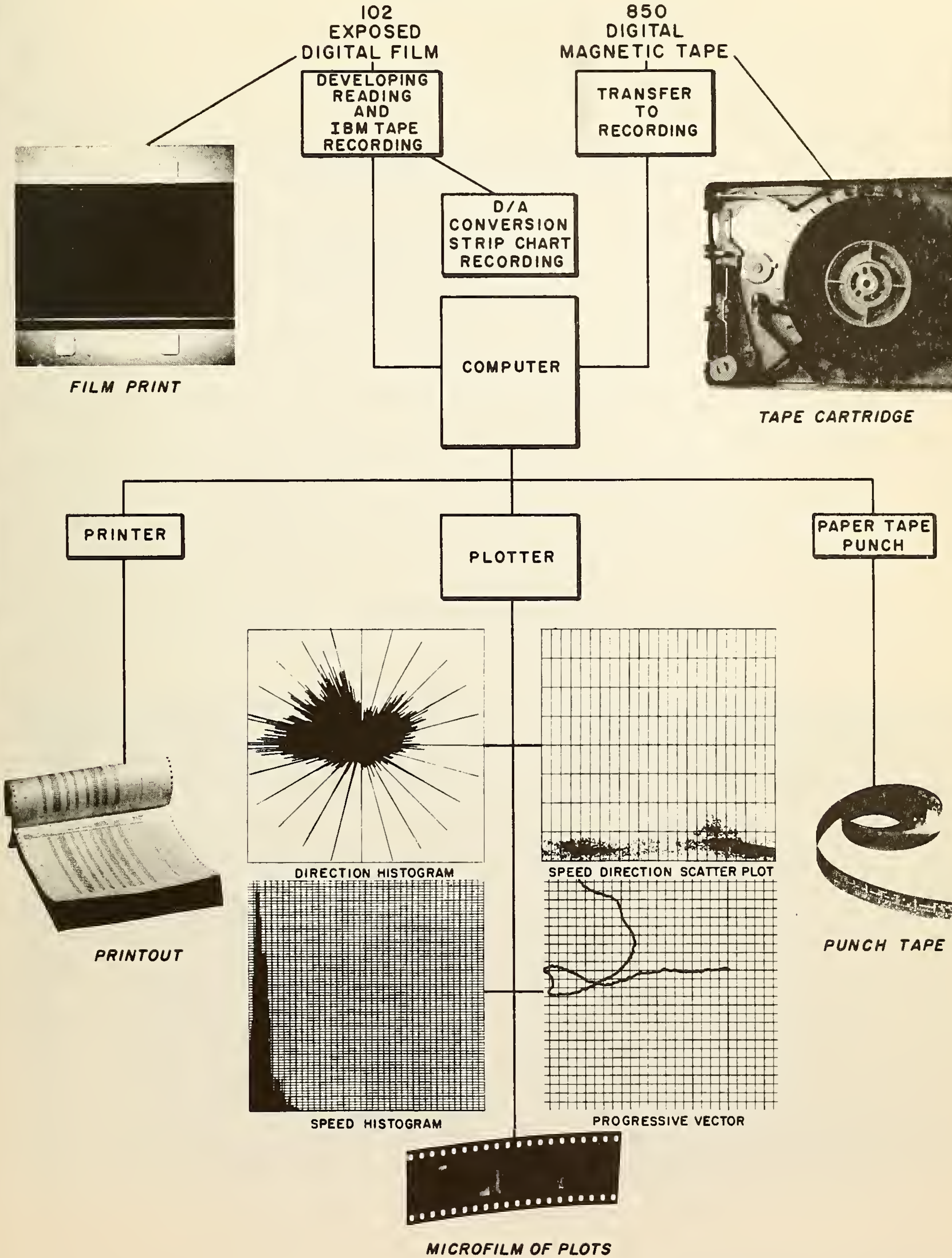
DATA PROCESSING SERVICES

To enable scientists and engineers to make effective use of the large amount of data collected by EG&G recording current meters, a wide variety of data processing services is available. The most common services are listed below:

- Special high contrast film developing, duplicating and edge numbering (Model 102 only).
- Generation of seven channel IBM computer compatible magnetic tape for computer input.
- Six channel analog strip chart, plotting compass, vane, computed current direction and inclinometer when included (Model 102 only).
- Computer magnetic tape for octal printout, graphic plotting or punch paper tape.
- Numerical printouts.
- Punched paper tapes of averaged values.
- Plots: a) speed versus direction scatterplot, b) set of five direction histograms, c) speed histogram, d) progressive vector plot, e) speed and direction versus time plot.

EG&G will store record duplicates of Model 102 film and Model 850 tapes to expedite further processing services if the user desires it.

DATA PROCESSING SERVICES



SPECIFICATIONS

	Model 102-0, 102-1	Model 850
Recording Method	Black & white photographic 16mm x 100 ft. film	Digital Magnetic Tape 1/4"x 390 ft. endless loop cartridge
Information Code	Current speed: number pulses per data frame. Direction: 7 bit Gray code	Current speed: 10 bit binary word. Direction: 7 bit Gray code
Compass	Both 102 and 850 employ damped magnetic compasses with accuracy at zero tilt ±3. Resolution: 2.8°.	
Vane	For both 102 and 850: Sensitivity at 0.25 knots to full range: 2°. Resolution: 2.8°.	
Rotor	For both 102 and 850: starting speed <0.05 knots. Linearity: linear above 0.4 knots. Accuracy: (vertical attitude) ±0.05 knot to 1 knot; ±0.1 knot to full speed	
Current Speed	102-0: 0-4 knots (or 0-2 knots) 102-1: 0-8 knots (or 0-4 knots)	0-7 knots
Sequency Timer	Both 102 and 850: EG&G timer provides accuracy of ±10 seconds per day.	
Power	Both 102 and 850: Self-contained ±12 volt parallel cell battery.	
Weight	Air: 120 lb Water: 30 lb	Air: 150 lb Water: 40 lb
Dimensions	69 inches long 8 1/2 inches diameter	72 inches long 8 1/2 inches diameter
Load Bearing	Both 102 and 850: Up to 5,000 lb tensile load across instrument in a mooring system.	
Finish	Both 102 and 850: Epoxy paint over hardcoat process. Rotor and vane coated with copper antifouling paint.	

ACCESSORIES, OPTIONS

Inclinometer (Standard on Models 102-0, 102-1)	Used with Model 102 (or 850) to measure inclination angle of the current meter from the vertical. This information is used to calculate horizontal current speed or to indicate mooring malfunctions.
Current Fin	Heavy duty aluminum fin. Clamps to either Model 102 or 850. Used to improve data quality by reducing short term axial rotation where present.
Surface Buoys & Accessories	EG&G offers surface buoys, release devices, radar reflectors, buoy lights, radiolocating, transmitters useful for ocean implantments of current meters.
Model 992-0 Digital Display Monitor	A highly desirable piece of test equipment for magnetic tape recording current meters.
Spare Parts Kits	Kits containing replacements for parts subject to wear are available for 102 and 850.
Tape Conversion and Playback Equipment (for Model 850 and other tape recording instruments)	1) Tape Record and Playback Module 2) Serial-to-Parallel Converter Module 3) Digital-to-Analog Converter 4) Strip Chart
Special Antifouling Finishes and Coatings.	Available on Request

All specifications subject to change. For more information, contact your nearest representative.

EG&G
ENVIRONMENTAL EQUIPMENT DIVISION
151 BEAR HILL ROAD · WALTHAM, MASSACHUSETTS 02154 · TELEPHONE: (617) 899-3710

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A PRACTICAL PORTABLE TIDE GAGE

BY ALFRED C. REDFIELD

Made in United States of America
Reprinted from LIMNOLOGY AND OCEANOGRAPHY
Vol. 7, No. 2, April, 1962
pp. 262–265

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A PRACTICAL PORTABLE TIDE GAGE

by Alfred C. Redfield

A Practical Portable Tide Gage[1]

This instrument was devised for use in a study of the hydrography of a shallow estuary and the related development of the associated marsh land. While it is not original in principal or design, it is described because it has proven to be reliable and precise and should be useful in a variety of hydrographic, geological, and ecological investigations at places where tidal data are unavailable.

The instrument has the advantage that it may be assembled from commercially available parts, may be installed in places where

[1] Contribution No. 1238 from Woods Hole Oceanographic Institution.

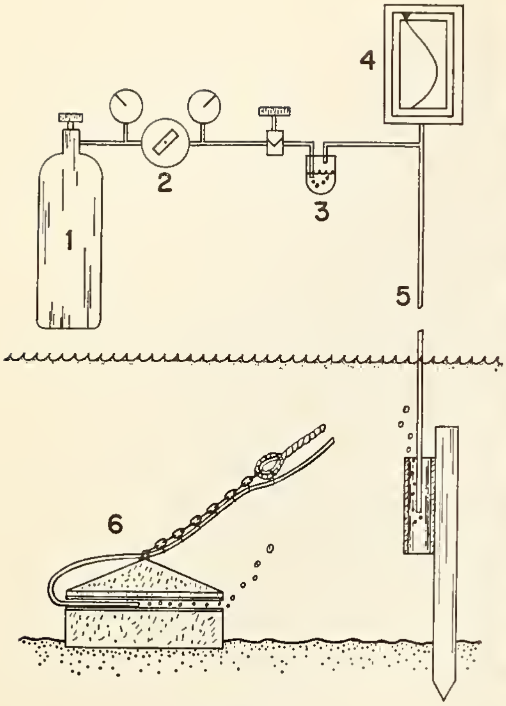

FIGURE 1

FIGURE 2

wharfs are not available, or in an anchored boat, and may be easily transported and rapidly set in operation.

In principal the gage depends on recording the pressure at which bubbles of gas escape from an orifice in a fixed position below the sea surface. The components required are listed below and their arrangement is shown in Figure 1.

1.) Source of compressed air or other gas.
2.) Device for controlling pressure in the system.
3.) Device for controlling flow of gas into the system.
4.) Pressure recorder.
5.) Tube leading to an underwater orifice.

The components used were:

1.) Aqualung tank—one filling serves for several months operation.
2.) Standard reducing gage—low pressure line to be maintained at about 10 lb.
3.) Needle valve and automobile sediment trap. The latter is modified so that the intake is below a surface of kerosene. Needle valve is adjusted to permit passage of 60–180 bubbles/min.
4.) Bristol Water Level Recorder Model 29 using a strip chart and designed for a range of 0–25 ft of water. An excursion of the stylus of 0.2 in. is equivalent to a change in depth of 1 ft and may be read by interpolation to 0.10 ± 0.05 ft. This instrument is suitable for tidal ranges of 5 to 15 ft and may be modified by changing the linkages to operate at tidal ranges of 2.5–7.5 ft. The clockwork will run for 8 days without rewinding. Chart provides for 33 days observation at ¾ in./hr.
5.) Tube leading to underwater orifice. For installation where the foreshore is steep, the gage may be mounted above the high water level and ⅛-in. I.D. copper refrigerator tubing led to a stake driven below low water. The orifice may be protected from fouling by drifting weed, *etc.* by a short length of ¾-in. pipe. Where the foreshore is broad, the gage may be mounted in a boat and heavy walled ⅛-in. I.D. rub-

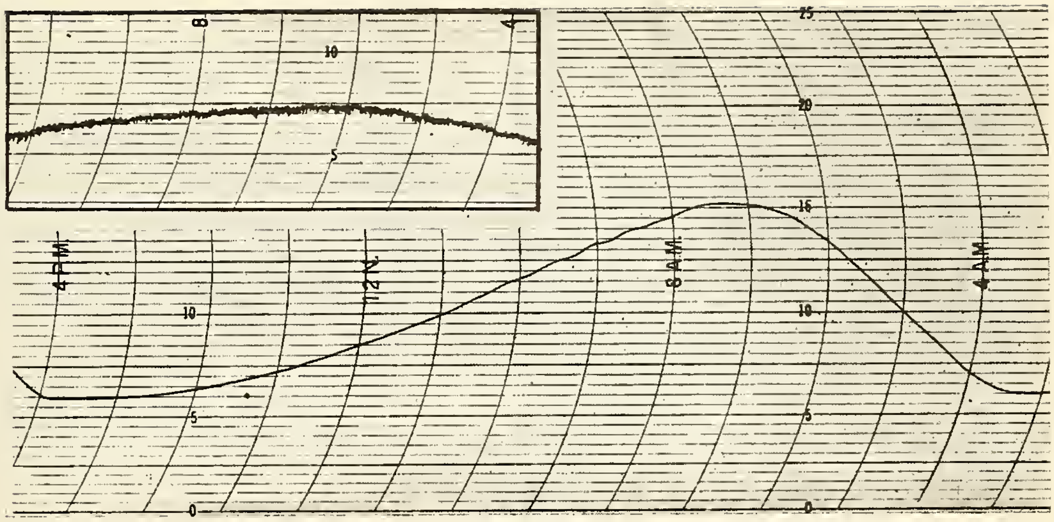

FIGURE 3

ber pressure tubing may be led down the mooring rope to connect it with an orific in the mooring block. Either arrangement can be used where a suitable wharf is available.

In using the instrument from an anchored boat, a mooring must be used which will not drag or foul with the swinging of the boat. The mooring devised is illustrated in Figure 1. It consists of a concrete block 14 in. on a side and 9 in. high in the top of which a short length of chain is embedded. The upper part of the block is beveled to avoid fouling. A piece of ¾-in. brass pipe is embedded in the block—parallel with its under surface and just below the bevel. The rubber pressure tubing is lashed at intervals to the mooring rope and to the chain at its junction with the block. Its end is passed into the brass tube and lashed in position. This mooring, which weighs about 180 lb, has held a 12-ft skiff containing the gage in an exposed position and in strong tidal currents for more than a month without dragging or fouling.

Figure 2 shows the assembly mounted on a marsh bank. A typical record obtained in a salt marsh creek is illustrated in Figure 3. Records continuous for 29 days have been obtained during two periods with the instrument mounted on shore and during two with the gage installed in a moored boat.

Under ordinary harbor conditions the instrument requires no damping to eliminate the effects of short period surface waves. The effect of wind waves under extreme conditions is illustrated by the inset in Figure 3, a record made in Great Harbor, Woods Hole, during a gale. Oscillations of longer period are recorded as shown in Figure 3 during the falling tide. In testing this type of gage from a pier at Atlantic City, the U. S. Coast and Geodetic Survey found that long-period swell disturbed the record—an effect which was damped out by introducing capacity into the air line.

A tide staff should be installed near the instrument and read whenever it is visited. This provides a calibration of the record, a check on its linearity, and a means of tying-in the record with a bench mark. It also controls effects due to changing density of the water and any malfunction of the instrument which may develop due to shifts in the position of the orifice, *etc.*

The precision of the record is indicated by a comparison of the individual readings with those of the calibration curve obtained with the tide staff. In the case of 97 readings obtained at 5 different installations at all stages of the tide, the standard deviation

of the differences between the record and the calibration curve was ± 0.06 ft. The differences are due to errors in reading the staff (± 0.02 ft) and in reading the record (± 0.05 ft). A comparison of records of the corresponding high water levels at Boston and at Barnstable during 186 tides indicates that the difference between the staff readings at these positions is independent of the changing amplitude of the tide. The differences of the individual pairs of readings from their average has a standard deviation of ± 0.11 ft. These differences depend on the errors in reading two gages and on differences in the actual elevations as they may have been affected by meteorological phenomena at positions 70 miles apart.

Water-level recorders are available in which a bellows at the underwater termination is used to sense the pressure at a fixed depth. Tide gages of this type are in use by the Canadian Hydrographic Service. Such gages eliminate the gas tank and control devices of the bubbler type gage. The latter has the advantage of reducing the underwater installation to the utmost simplicity at the point where leaks and marine fouling are likely to give trouble.

ALFRED C. REDFIELD

Woods Hole Oceanographic Institution.

APPENDIX D

MASSACHUSETTS PORT AUTHORITY

STAFF STUDY

AIRFIELD IMPROVEMENTS

AT

LOGAN INTERNATIONAL AIRPORT

May 24, 1971

APPENDIX D

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*This section of the Staff Study represents an analysis and report by Joseph M. Manning, President of Urban Transportation Systems Associates with Massachusetts Port Authority staff assistance.

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SUPPORTING DOCUMENTS

NO. 1 Analysis of Air Service Effects of a Night Curfew at Boston-Logan International Airport

NO. 2 Environmental Report by Fay, Spofford & Thorndike, Inc. Runway 15L-33R, Boston-Logan International Airport

NO. 3 Letter from Federal Aviation Administration to U. S. Army Corps of Engineers Dated 10 May 1971 (Analysis of Approach Slopes over President Roads Anchorage)

INTRODUCTION

1. Purpose

The purpose of this staff study is to provide additional supporting analysis and documentation for the draft Environmental Statement prepared for submittal to the Federal Aviation Administration and the U.S. Army Corps of Engineers, as required by the Environmental Policy Act, for major airport development actions which may significantly affect the quality of the environment.

2. Relationship to Consultants' Report

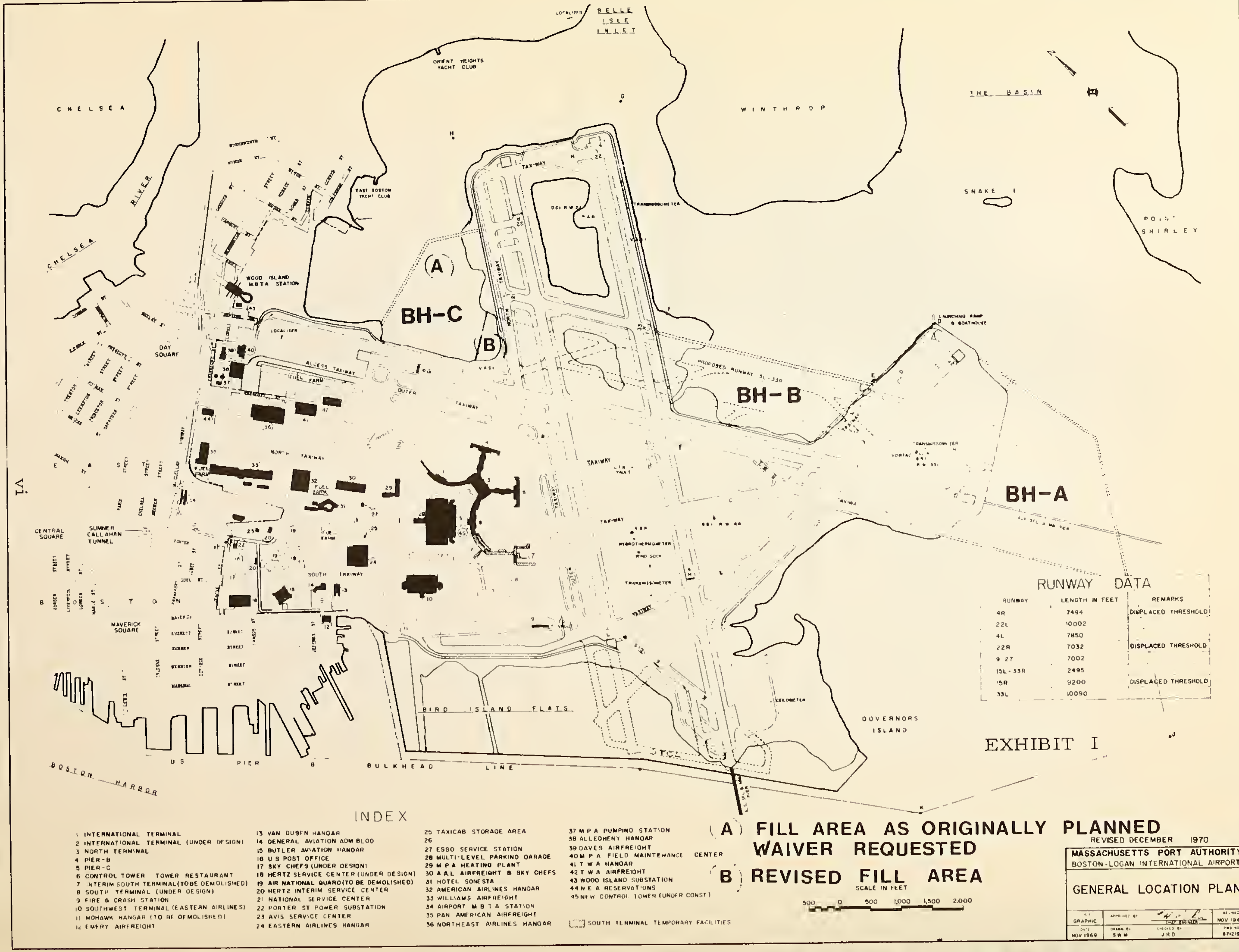
This staff study supplements the Consultants' Report, to which it is appended, by analyzing selected areas of possible environmental concern which were not studied by the Consultants or which were studied only in part. Environmental factors which are analyzed in depth in the Consultants' Report are not treated in this Appendix.

3. Project Description

The project improvements proposed at Boston-Logan International Airport are shown in Exhibit I and consist of the following basic elements:

a. Dikes, Interceptor Drains and Tidal Flat Dredging (Phase I)

- Permit application for this construction has been made to the U.S. Army Corps of Engineers.
- The work includes dredging, construction of earth and stone dikes,



CHELSEA
CHELSEA RIVER
BELLE ISLE INLET
ORIENT HEIGHTS YACHT CLUB
EAST BOSTON YACHT CLUB
WINTHROP
THE BASIN
SNAKE I
POINT SHIRLEY
WOOD ISLAND MBTA STATION
DAY SQUARE
CENTRAL SQUARE
SUMNER CALLAHAN TUNNEL
MAVERICK SQUARE
BOSTON HARBOR
US PIER B BULKHEAD LINE
BIRD ISLAND FLATS
GOVERNORS ISLAND
BH-A
BH-B
BH-C
(A)
(B)
PROPOSED RUNWAY 5L-33R
LAUNCHING RAMP & BOATHOUSE
TAXIWAY
NORTH TAXIWAY
SOUTH TAXIWAY
ACCESS TAXIWAY
OUTER TAXIWAY
FUEL FARM
LOCALIZER
RUNWAY DATA
RUNWAY | LENGTH IN FEET | REMARKS
4R | 7494 | DISPLACED THRESHOLD
22L | 10002 |
4L | 7850 |
22R | 7032 | DISPLACED THRESHOLD
9 27 | 7002 |
15L - 33R | 2495 |
15R | 9200 | DISPLACED THRESHOLD
33L | 10090 |
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SOUTH TERMINAL TEMPORARY FACILITIES
(A) FILL AREA AS ORIGINALLY PLANNED WAIVER REQUESTED
(B) REVISED FILL AREA
SCALE IN FEET
500 0 500 1,000 1,500 2,000
REVISED DECEMBER 1970
MASSACHUSETTS PORT AUTHORITY
BOSTON-LOGAN INTERNATIONAL AIRPORT
GENERAL LOCATION PLAN
GRAPHIC
NOV 1969
SWM
JRD
NOV 1969
671219

slope protection and drainage appurtenances in three areas contiguous to the existing airport.

- More specifically, the dredging work is in water depths of approximately 10 to 20 feet and covers an area 2,000 feet long by 170 feet wide. The quantity of dredged material is approximately 250,000 cubic yards.
- The earth dike sections are to be constructed in shallow water with granular material. The total length of earth dike included in the project is 5,650 linear feet. The top width of the dike is 32 to 50 feet with 2 to 1 side slopes. The total quantity of material required for the earth dike is 717,000 tons.
- The stone dike sections are to be constructed at locations where the water depth is 10 to 30 feet. Durable crushed stone is to be used for this type dike construction. The top width of the dike is to be 15 feet with 1-1/2 to 1 side slopes and the length of the dike included in the projects is 5,850 linear feet. The total quantity of stone material required is 1,163,000 tons.
- Both the earth and stone dikes are to be protected on the seaward side with large size armor stone. The total quantity of this protective stone which extends from the top of the dike to below water level is 93,000 tons.
- It is anticipated that dredging will be accomplished by barge

mounted crane and bucket. Dredged material may be moved to disposal site by barge or pipeline or a combination of this equipment. Stone dike material may be placed by bottom dump scow or end dumped from trucks while earth dike material will probably be end dumped from trucks. It is anticipated that armor stone will be transported by truck and placed by crane working from the dike structure.

b. Land Fill, Surcharge and Temporary Drainage (Phase II)

- Permit application for this construction has been made to the U.S. Army Corps of Engineers. This work involves the placing of clean, granular borrow fill within the dike perimeters, surcharging the fill and the installation of temporary drainage.
- The total quantity of fill material required is estimated at 5,500,000 cubic yards, covering a combined area of approximately 196 acres.
- Borrow fill will most likely be transported by truck and end dumped at the construction site although other alternatives are possible.

c. Airfield Improvements (Phase III)

- New Parallel Runway 15L-33R
  - A new runway 1,200 feet from and parallel to existing Runway 15R-33L, together with associated taxiways, overrun at the 33-R end and sites for navigational aid facilities.

- Construction work entails excavation and disposition of the surcharge, grading, installation of permanent drainage and the paving, lighting, grooving and marking of a 9,200 foot by 200 foot heavy duty runway with 35 foot paved snow shoulders. The lighting includes centerline lighting and in-runway touchdown lighting in the 15L end with pots only, installed in the 33R end.
- These facilities are the only airfield improvements associated with Phases I and II of the construction work described above.

• Extension of Runways 4L and 9
  - Extension of Runway 9 by approximately 1,900 feet and Runway 4L by approximately 1,200 feet, together with associated taxiways.
  - Construction work entails installation of drainage and the paving, lighting and marking of these improvements. Landing thresholds will remain at their present locations on Runways 4L and 9.

• STOL Runway 15-33
  - A new STOL Runway approximately 2,400 feet in length, together with associated taxiways.
  - Construction work entails installation of drainage and the paving, lighting and marking of the new facilities.

  (NOTE: The latter two airfield improvements will be

located within the Bird Island Flats area where filling operations commenced prior to May 27, 1970, and thus required no permit from the Corps of Engineers.)

SECTION I

AIRCRAFT NOISE ALTERNATIVES

SECTION I

AIRCRAFT NOISE ALTERNATIVES

INTRODUCTION

This section of the Study is concerned with an analysis of alternative means which have been suggested for alleviating the noise problem, a subject which is not covered in detail in the Consultants' Report.

SUMMARY OF FINDINGS

Of all the alternatives considered for alleviating the impact of aircraft noise, none are as feasible nor as effective without serious economic and air service penalties as is the program proposed by the Massachusetts Port Authority.

A. BANNING OF 4 ENGINE JETS

1. One proposed means of alleviating noise exposure is a ban on all four engine jet aircraft operating out of Logan. While it is true that four engine aircraft, other than the 747, produce somewhat higher noise levels, the severe impact of such a ban on the air transportation industry and on the general public dependent upon that industry would be far too great a price to pay for the minor improvement in overall noise exposure thus created.

    a. Four engine jet operations account for less than 25% of total air carrier movements at Logan today. Of these, considerably less than half comprise the earlier turbojets which generate the greatest noise levels. In addition, these are the aircraft scheduled for

earliest retirement - to be replaced with far quieter "new technology" aircraft. By 1975, only 18% of the total air carrier movements are projected to be four engine jets and only 4% the early turbojet types. It is also forecast that, by 1975, "new technology" turobans, including both three and four engine configurations, will constitute at least 18% of the total air carrier traffic operating at Logan. These trends will continue to accelerate and would negate the initial noise reduction benefit which would be gained by an arbitrary ban on four-engine jet aircraft.

b. Since the total fleets of all airlines serving Boston are presently composed of approximately 48% four engine jet equipment and only 28% three engine jet equipment, there would be insufficient numbers of the latter types available for equipment substitution, even if their operating ranges were adequate to fly the trip lengths necessary.

c. The operating ranges of three engine jet aircraft are insufficient to serve many of the non-stop routes flown by four-engine jet equipment. A ban on four-engine jets would immediately result in the loss of all non-stop transatlantic and transcontinental air service from Boston which served nearly one million passengers in 1970. Co-terminus cities would also lose all transatlantic air service through what had previously been the regions only major international gateway.

d. The impact on cargo, which depends almost exclusively on four-engine jet freighter equipment for "all cargo" operations, would be to effectively

cripple this vital service to the industry of the region and to depress the economy which it nourishes. The effects created would be similar in nature but even greater in overall impact than those of a night curfew. This latter subject is covered in Chapter IX of the Consultants' Report and as a separate alternative under this heading.

2. Legally, this proposal falls within the category of interference with interstate commerce and conflicts with the supremacy clause of the Constitution. As such, the Authority believes that such a ban would be unconstitutional if imposed.

B. MAXIMUM NOISE LEVEL RESTRICTIONS

1. A second proposed means of alleviating noise exposure involves the establishment of maximum permissible noise levels for aircraft operating into or out of Logan International Airport, either by Port Authority regulation or local legislative action. Aside from legal questions of the Authority's power to institute such action or the constitutionality of local legislation to require it, the Port Authority cannot endorse this means of achieving the objective of noise relief to airport communities for reasons summarized below:

   a. An individual airport, within the network of airports which collectively make up the national airport system, is not an entity in itself but a functioning part of the system as a whole.

   b. To subject an individual airport to restrictive noise regulations independently of others would not generate sufficient incentive to bring about industry compliance nationally (Boston traffic represents only 3% of total

U.S. traffic). The result would only be to penalize the local communities concerned through derogation in air service provided.

c. Independent noise level restrictions established on any significant scale throughout the national airport system would create chaos in the industry due to a lack of conformity in such restrictions and the inability of the industry to meet the various standards imposed.

d. The only reasonable and effective means of establishing maximum noise level restrictions for air carrier airports would be federal government regulation applied uniformly and with a timetable for attainment which the industry can realistically meet without precipitating a breakdown of our national air transportation system.

2. In the opinion of the Massachusetts Port Authority, it could not itself impose and enforce maximum noise level restrictions nor could such restrictions be imposed and enforced by the Commonwealth of Massachusetts.

a. Since the establishment and enforcement of maximum noise level restrictions, stringent enough to significantly reduce noise levels, would result in derogation of air service, the Authority would be prohibited from taking such action under the provisions of its Enabling Act.

b. The establishment and enforcement of maximum noise level restrictions by the State of Massachusetts would clearly fall within the category of interference with interstate commerce and conflict with the supremacy clause of the Constitution. As such, legislative action to implement and

enforce these restrictions would be unconstitutional.

- Under Public Law 90-411, Congress has vested in the Federal Aviation Administration the responsibility for adopting regulations which would achieve aircraft noise reduction compatible with the national interest and interstate and foreign commerce. Since the FAA has acted under its rule making power to discharge that responsibility, it is apparent that the federal government has pre-empted the field of aircraft noise regulation.
- The constitutionality of the California noise regulations, scheduled to take effect at the end of this year, has not yet been tested in the Courts, but they are unconstitutional in the opinion of most observors.

C. SURCHARGE FOR NOISIER AIRCRAFT INCLUDING A NIGHT DIFFERENTIAL

1. Another proposed means of alleviating noise exposure involves the use of financial incentives or penalties to induce airlines to operate quieter aircraft and to schedule flights during daytime hours. The basic fallacy in this approach is that landing fees do not provide sufficient economic leverage to induce the airlines to take advantage of the savings or avoid the penalties which such a system would provide.

   a. Landing fees at Logan only represent approximately 1% of total airline expenses incurred as a result of operating from that facility.

   b. The airline expenses which would be incurred in substituting or acquiring quieter jet equipment for system routes including Boston and in reducing

daily aircraft utilization time to schedule flights outside of nighttime hours, would be vastly greater than the minor savings from the Logan incentive.

2. Landing fee differentials could probably be established by the Authority providing they bore some reasonable relationship to the costs of operating the airport and to the services required. However, a differential which was merely a penalty for using the airport at a given hour or for operating one aircraft which produces more noise than another would probably be unenforcable.

D. NIGHT CURFEW

An often proposed means of alleviating noise exposure is the establishment of a curfew on all aircraft movements during the nighttime hours, usually considered to be the period between 10 or 11 P.M. and 7 A.M.. The direct economic impacts of pursuing this course of action are presented in Chapter IX of the Consultants' Report, and will not be specifically dealt with here. However, the implications are so severe that the Port Authority is and, under its legislative mandate, must be opposed to this concept which would make Boston the only city in the country without air service during the nighttime hours due to a curfew and insure its relegation to a second class air service hub.

1. Any constraints placed upon an air carrier airport within the air transportation system will act to constrain the system as a whole due to the complex and interrelated factors which effect the functioning of the system.

   a. Geography and time zone differentials.

   b. Aircraft utilization and equipment routing requirements.

c. Inter-dependency of flight schedules which provide the intricate and interwoven system of through and connecting services between the hundreds of air carrier airports here and abroad.

d. Need to terminate final daily schedules at those airports from which the aircraft will originate next morning departures.

e. Necessity of terminating final daily schedules only at those airports with facilities for overnighting the aircraft and for scheduled maintenance and inspection operations.

2. Although aircarrier operations at Boston-Logan International Airport between 11 P.M. and 7 A.M. constitute less than 10% of total daily operations, the local as well as world-wide air service effects of a curfew would be substantial. Based on a September 1969 air service analysis of these effects, it was found that passenger service between Boston and 65% of all 267 cities served, here and abroad, would be affected, many by substantial percentages of total service available. Impact on "all cargo" service was much more severe with schedules between Boston and 70% of all 44 cities served affected, most by substantial percentages and with 17 cities losing 100% of all service in one or both directions. A summary of this air service analysis will be found in the Supporting Documents section of this Study.

3. Evaluation of the significance attached to a night curfew at Boston must consider a variety of factors.

a. Passenger Service

- Most passenger flights during the curfew period are arrivals, following completion of each aircraft's daily use on system routes. This positions them for morning originations and for night maintenance and inspection operations.
- Due to scheduling and positioning commitments elsewhere, many late arrivals would have to be cancelled together with the morning originations which they would otherwise generate.
- Loss of air service for the people and businesses of this area.
- Significant slowdown in the delivery of the U.S. Mail.
- Denial of opportunity for the public to take advantage of night coach rates.
- Adverse economic effects on the community resulting from air services losses.

b. Air Cargo Service

- A night curfew would have serious effects on air cargo service by denying the dispatch and receipt of air freight through the Boston gateway during the hours when the demands of the industry most require it.
- Industry is heavily dependent on air cargo service and its ability to provide overnight delivery to virtually any distant point.

- Development of air cargo service has changed the whole pattern of product logistics in many industries by drastically reducing inventory and warehousing requirements here and overseas.
- Functioning of the air cargo system requires late night departures and early morning arrivals to meet the demands of the service which it provides.
- Air cargo has become an essential business tool without which industries in this area could not effectively compete in today's markets.
- The competitive disadvantage to industries without adequate air cargo service could create a strong inducement to relocate elsewhere.
- Severe economic and employment impact on the trucking companies, air freight forwarders and the airlines who provide this essential service.
- Serious economic penalties on the local area in general.

4. The Massachusetts Port Authority is not unmindful of the noise impact on surrounding communities, particularly at night, and has, in fact, committed itself to positive programs to reduce the impact during these hours.

   a. The Authority maintains a periodic monitoring program to review the necessity for each carrier operation scheduled between the hours of 11 P.M. and 7 A.M.. Some progress has been made in encouraging and influencing the airlines to schedule only the minimum level of operations necessary during these hours, consistent with actual air service

requirements of the Boston area. This program will be agressively pursued on a more frequent and continuing basis.

b. The Authority has developed and is working toward implementation of a modified concept of preferential runway use which will maximize over-water approaches and departures whenever adequate peak hour capacity will permit. Since operations between the hours of 11 P. M. and 7 A. M. coincide with the period of lowest demand, there are minimal capacity constraints and operations can be conducted on runways furthest removed from residential areas a very high percentage of the time. This program will be developed on a priority basis in conjunction with the FAA and the Airlines and is essential to minimize noise exposure in the vicinity of Logan. Once implemented, it will provide an extremely effective noise reduction technique, particularly during the nighttime hours when noise sensitivity is greatest. (See Appendix A for details)

5. There is a serious doubt on Constitutional grounds that a night curfew could be established and enforced by legislative action.

E. COMPATIBLE LAND USE

This category of noise alternatives includes several types of indirect actions which have been proposed as means to alleviate the impact of aircraft noise.

1. Soundproofing of Homes and Public Buildings

a. As detailed in Chapter III of the Consultants' Report, the effectiveness of soundproofing as a means of reducing noise annoyance is open to serious question.

- The most comprehensive study yet undertaken in the field of community reaction to airport noise, recently completed under NASA contract by Tracor, Inc., concludes that soundproofing as a means of residential noise attenuation is not effective.

b. For a variety of reasons, soundproofing as a noise alternative is not a practical solution for general application.

- The cost of a comprehensive program would be realistically beyond the financial resources of any entity today.
- The very low correlation between existing methods of noise measurement and noise annoyance prediction provides no realistic basis for establishing geographic boundaries for soundproofing applicability or extent of noise insulation.
- Types of construction and condition of structures vary so widely that soundproofing could be more expensive than the property is worth or it could be more feasible to build a new structure than soundproof the old one.

c. Under the provisions of the trust agreement between the Massachusetts Port Authority and the trustee, under which all Authority bonds have been sold, the Authority may expend its funds only in connection with the operation of projects under its control. It would, therefore, not be possible for the Authority to expend revenue to soundproof buildings not owned or operated by it or not essential to the operation of any of its projects.

2. <u>Property Acquisition</u>

a. The concept of property acquisition by an airport operator as a means of reducing noise annoyance has limited applicability in the case of Boston-Logan International Airport.

- To be effective, in an overall sense, large scale purchases would be necessary which would have the undesirable result of serious disruption to neighborhood communities.
- Noise reduction at its source and the capability for operational flexibility to minimize community overflights are far more effective and non-disruptive alternatives which are being actively promoted by the Port Authority.
- The purchase of land and homes lying directly within the runway approaches is a desirable objective particularly when the property is offered to the airport operator on a voluntary basis. It is the policy of the Massachusetts Port Authority to implement this objective on a selective basis, each case being judged on its respective merits.

3. <u>Replacement Housing</u>

a. This is an extension of the property acquisition concept to minimize community disruption by providing replacement housing for those persons displaced.

- The Authority has no objection to the basic principal of replacement housing providing it is limited to close-in areas under runway approaches.

- The Authority would not be legally able to undertake such a project, either under the terms of the Enabling Act which created it or under the terms of the trust agreement which limits allowable expenditures to projects owned by the Authority.
- Were it possible to remove these legal obstacles, a project of this magnitude would realistically have to be a joint project, perhaps sponsored by the Port Authority but with the voluntary participation of the communities involved.

4. Avigation Easements

a. Avigation easements are of limited value legally and provide no noise relief in themselves.

- While there would be no legal ban to the purchase of avigation easements, within runway approaches, they are of a limited value from a legal standpoint due to the great difficulty in drafting the instruments so as to make them applicable to aircraft not in existance at the time the easements were granted. Since avigation easements do not in any way reduce the annoyance or provide noise relief, they cannot be considered as an alternative to the Port Authority improvement program which will provide these benefits.

. PREFERENTIAL RUNWAY USE

Of all the alternatives considered above for reducing noise exposure, and with the exception of noise reduction at the source, the implementation of a rigid and comprehensive preferential runway use system offers the greatest potential for substantial

noise abatement without producing unreasonable penalties on the airport user.

1. The Massachusetts Port Authority in conjunction with R. Dixon Speas, who conducted computer analyses of the problem, have developed a modified concept of preferential runway utilization which designates the use of runway combinations producing the least noise exposure whenever the capacity of those combinations is adequate to handle the traffic without unacceptable delays and is within acceptable crosswind criteria. The noise benefits which such a system is capable of providing is clearly demonstrated in Chapter III of the Consultants' Report.
2. Since the degree of noise abatement possible is dependent upon adequate capacity at peak periods, the full potential of the system can only be realized by the addition of new parallel Runway 15L-33R which will minimize capacity constraints.
3. A detailed analysis of the methodology used in developing this concept is contained in Appendix A.
4. The Authority is committed to implementation and enforcement of this system as one significant means of reversing the former trend of increasing environmental noise impact on surrounding communities.

SECTION II

ALTERNATIVES TO AIRPORT IMPROVEMENTS

SECTION II

ALTERNATIVES TO AIRPORT IMPROVEMENTS

INTRODUCTION

This section of the Study discusses a variety of suggested alternatives to the proposed project improvements at Boston-Logan International Airport in terms of their feasibility and effectiveness in negating the need for these improvements.

SUMMARY OF FINDINGS

All of the alternatives suggested have been analyzed in detail and it is the studied conclusion of the Massachusetts Port Authority that none of these alternatives are as practical, feasible or environmentally desirable as the improvement program proposed at Boston-Logan International Airport, nor would they provide realistic solutions to the need for these improvements within the time frame necessary to meet the near term transportation requirements of the Boston region.

A. HIGH SPEED RAIL

1. Background

a. It is well recognized by the transportation industry that the development of a transportation system within the Northeast Corridor balanced between highway, rail and air modes is essential if the future travel demands in this region are to be met. A vital element of this system

is the development of high-speed rail facilities competiti...
with air travel in terms of travel time, comfort, convenience and service.

b. The need for a high-speed rail system in the Northeast Corridor has been recognized for at least ten years, during which time many studies have been conducted and, more recently, small scale experiments carried out with the Metroliner and Turbotrain. While these experiments have indicated a definite potential, progress toward a viable, competitive and economically feasible system has been painfully slow.

c. The concept of high-speed rail service encompasses three principal systems and technologies in the near term, medium term and far term time frames.

   - Improvement of conventional rail systems and equipment to provide ultimate speeds on the order of 150-200 mph by the 1980's. These improvements are within the capability of present technology.
   - Technological development of Tracked Air Cushion Vehicles (TACV's) or Fluid Suspension Vehicles with ultimate speeds on the order of 200-300 mph.

A transportation system utilizing vehicles of this type will probably not be a reality before the 1990's.

- Technological development of vehicles operating within surface or underground tubes having an ultimate speed potential of up to 500 mph. Development of a transportation system utilizing these systems would be unlikely in the opinion of the Authority before the turn of the century.

d. Due to the short term requirements for improved airport facilities to accomodate anticipated demands, further discussion of the high-speed rail alternatives will be limited to development possibilites for conventional rail systems during this decade.

2. Market Potential Realization

a. The only major market in which high-speed rail could effectively compete with air service from Boston-Logan International Airport, in terms of travel time, is in the Boston-New York market.

b. A travel time between Boston and New York of not more than 2-1/2 hours by high-speed rail is considered necessary if it is to be competitive with air service.

c. Other factors in addition to travel time will determine the degree of market penetration by high-speed rail.

- Convenience, cleanliness, comfort and courtesy of service.
- Station facilities and services equal to air terminal facilities and services to which the air traveler is accustomed.
- Ground transportation facilities at terminus points for automobile parking, rental cars, and public transportation competitive with those provided at airport facilities.
- Preference for air travel by a significant segment of those accustomed to this mode.

d. Assuming that travel time by high-speed rail can be reduced from the experimental turbotrains' running time of 3 hours and 40 minutes to 2 hours and 30 minutes or less before 1980, some air service market penetration may be anticipated. However, the Authority believes this penetration would not be very significant, at least until such time as <u>all</u> facets of the service become fully competitive, a possibility considered extremely unlikely before 1980.

3. Feasibility and Cost Versus Running Time

a. The achievement of a 2-1/2 hour running time between Boston and New York is technically feasible but will require extensive modification and improvements of roadbeds, rails, curve radii, grade crossings and signal systems. Even shorter running times are technically possible, but costs escalate very rapidly for small increments in running time saved. To achieve a running time of 2 hours, for example, the total system cost has been estimated by responsible industry sources at more than 1 billion dollars.

- A report by the Systems Analysis Research Corporation entitled, "Feasibility of High-Speed Rail Service", published in October 1969, estimates the following costs versus running times for a high-speed rail system linking Boston and New York. This Report proposed the use of electrically powered vehicles to minimize right-of-way pollution.

Route	Mileage	Best Running Time	Construction Costs (1) (millions)
Upgrade existing route	228	3 hours	$280
Revised existing route	218	2-1/2 hours	$487
New inland route	208	2-1/3 hours	$539

(1) 1969 Dollars

- The use of turbine powered trains on the Boston to New York route may be more feasible than electric power which would require a heavy investment in electrification facilities. Experience with the experimental turbotrain, on the other hand, as well as with the turbo trains operating in Canada, indicates very substantial operation and maintenance expenses will be incurred.

4. <u>Environmental Factors</u>

a. The belief that high-speed rail operations have little or no environmental impact, in comparison to those aircraft operations which they may replace, is not a valid one.

- Airfield improvements proposed involve no land taking or community dislocation.
- Right-of-way improvements and relocations to achieve high-speed rail running times of 2-1/2 hours or less will involve land takings and community dislocation becoming very substantial as the 2 hour mark is approached.
- Air field improvements proposed will result in reduced noise and air pollution exposure to adjacent communities

- The high-speed rail right-of-way will expose abutting communities along its entire 200 odd mile length to increasing levels of noise and air pollution as service expands.

5. Economic and Developmental Restraints

   a. The economic problems associated with a competitive high-speed rail system are formidable.

      - The development of a fully competitive system necessary to market penetration will be an extremely expensive project carrying high investment amortization costs in addition to heavy operation and maintenance expenses for roadbeds, equipment and station facilities.
      - There is a serious question whether these costs can be absorbed by revenues generated, without substantial government subsidy, while maintaining fares at a competitive level.
      - There is much uncertainty as to the market penetration which can be attained versus various levels of development costs and associated running time.
      - The long investment amortization period needed also

tends to restrain a major financial commitment to the existing rail system when new technology developments in this field could obsolete it long before the original investment could be retired.

b. Organizational factors associated with the coordination, decision making and funding aspects of such a complex interstate project, involving many and diverse governmental and private interests, has acted to slow the pace toward implementation of a system in being.

- The establishment of the Office of High-Speed Ground Transportation within the Department of Transportation and the recent formation of AMTRAC have been significant steps forward but they are severely hampered by budgetary limitations.

6. Development Time

All of the aforementioned factors considered, the Massachusetts Port Authority can see no possibility that a viable and competitive high-speed rail system will be developed to the point of significantly effecting short-haul passenger demand at Boston-Logan International Airport before 1980, if then.

B. V/STOL

1. Background

a. As a concept, V/STOL holds great promise as a short haul air transportation system which can operate independently of conventional air traffic and thereby greatly increase the capacity of existing airports for medium and long haul operations.

b. The concept of V/STOL is one which has been the subject of intensive study, experimentation and research over a period of years. Despite this effort, however, the actual development of a V/STOL system which can effectively and economically compete for the short haul air service markets is still very remote.

2. Current Status

a. A wide variety of projects are underway in the field of STOL development by the government, airlines, aircraft manufacturers and other research groups. Exhibit 2 provides a summary of these projects.

b. V/STOL development as a system involves three major system segments, i. e., aircraft, air navigation facilities and STOL landing facilities.

- V/STOL aircraft of sufficient seating capacity to realistically meet short haul passenger demands

EXHIBIT 2a

GOVERNMENT STOL PROJECTS

NASA

1. Generally, NASA is continuing its research and technology programs, coordinated with the FAA/DOT and DOD to provide the base of technology upon which industry can proceed with development and production of STOL transportation systems work.
2. A major new initiative in 1972 is the design and development of an experimental STOL turbofan transport research airplane with the essential objectives of validating the predicted performance and permitting the establishment of realistic criteria for certification of commercial subsonic STOL transport aircraft and for enroute and terminal area operations.
3. Conducting studies into specific configurations of the experimental STOL transport research aircraft based on the research done in FY 1971:
   - A. Lift Systems Analysis
   - B. Aircraft Flight Dynamics
   - C. Air Traffic System

DOT/FAA

1. The STOL avionics/air traffic control program was initiated in FY 1971 and closely coordinated with the offices of NASA in order to develop an optimum method of regulating air traffic.
2. A joint investigation with NASA to determine the major problems confronting the air transportation industry resulted in these proposals for continuing work:
   - A. DOT Program Office established to handle the problems involved with airport/aircraft noise.
   - B. Selected airports used to demonstrate and experiment in development of technology and procedures to ease airport congestion (i. e. V/STOL investigation).
   - C. Amend aircraft development programs to increase the share of funding provided by the Federal Government for airport grants from 50 to 67% with overall level of airport grants for runway expansion increased.
   - D. Funding for the conceptual design and analysis of economical vehicles for the STOL market in order to define an aircraft which would have the capacity, economic and performance characteristics to best serve low-density markets.
3. Development of a new V/STOL Special Projects Office which would foster the development of STOL and V/STOL transportation systems and encompass the full range of STOL and V/STOL, rather than dealing with one area.

CAB

1. Beginning phase 2 of the Northeast STOL Corridor Investigation in order to determine which air carriers will service the routes.
2. Conducted an analysis of passenger traffic in the major short-haul markets to gain a better understanding of competition among carriers, and to aid in alleviating airport congestion.
3. Concluded that existing airports (Boston-Logan International, LaGuardia) are not acceptable STOLport sites.

AIRLINES' STOL PROJECTS

AMERICAN

1. Floating Interim Manhattan STOLport (FIMS)

   Joint project with the FAA to determine the technical feasibility of, and to recommend the floating structure design best suited to the operation of a movable metropolitan STOLport located in the Hudson River. Although concerned with a particular site in Manhattan, the demonstration of its technical feasibility would indicate the general applicability of the floating STOLport concept at many other metropolitan sites.

2. Interim Propeller-Driven Design Proposals

   In the continuing evaluation of STOL design proposals American recently selected Canadair, deHavilland of Canada, Grumman Aerospace and McDonnell Douglas for further negotiations concerning a propeller-driven interim short takeoff and landing (STOL) aircraft for operations over their short-haul routes.

3. Other Continuing American Airlines Investigations

   A. Analysis of the economic viability of short-haul jet transport

   B. Investigation as to the probable timing of a jet STOL and whether it will be available soon enough to obviate the need for a propeller aircraft.

   C. Interim feasibility flight tests which is an extension of the previous Inter-Metropolitan STOL Evaluation, designed to investigate the potential of an integrated STOL Transport System for the expanding short-haul market.

EASTERN

1. STOL Jet Transport

   Working on the development of a jet STOL transport, with special consideration given to the area of noise tradeoff.

2. Joint American Airlines Project

   Proposal for a joint project to develop a propeller STOL transport.

3. STOL Evaluation Program

   Continuation of joint project with McDonnell Douglas as to the feasibility of integrating STOL aircraft into the already over-crowded Northeast Corridor.

PAN AMERICAN

1. Metro-flight

   Utilizing the Sikorsky CH-53, this study of intercity transportation which began in November has already conducted several test flights to determine the feasibility of an intercity transportation system.

REGIONAL AIRLINES

1. Committee on V/STOL Transportation

   This committee organized by the regional airlines will carefully examine the feasibility of V/STOL transportation.

MANUFACTURERS' STOL PROJECTS

SIKORSKY AIRCRAFT

1. A joint program with Pan Am which is investigating the feasibility of the intercity transportation concept through such things as demonstration flights.
2. Conducting an analysis of the operational and economic characteristics of the VTOL system.

HELIO AIRCRAFT

1. Studying the commercial feasibility of light (under 12, 500 lbs) STOL aircraft through investigation of such things as turbine-power, low cost/ high efficiency aircraft as opposed to helicopters.

ROLLS ROYCE

1. Contracted to NASA in a joint United States/United Kingdom project studying lift engine development. Other areas of research involve VTOL propellers, exploitation of foreign hardware and advancement of the propulsion system.

ALLISON DIVISION OF GENERAL MOTORS

1. Contracted to NASA in the above mentioned project for Rolls Royce.

LEAR-SIEGLER

1. Initiating work on a prototype flight director computer which permits autopilot control and navigation of V/STOL machines and helicopters under minimum IFR flight conditions.

GENERAL AIRCRAFT CORP.

1. Conducting a marketing group investigation as to the largest numerical requirement initially for regular airline type STOL aircraft, with considerations of frequency in relation to the traffic potential.

DE-HAVILLAND

1. Conducting an analytic and flight test work program directed specifically at the subject of STOLport planning and design.

BOEING

1. Studying various STOL configurations based on 100 passenger airplanes of the 737 type.
2. Investigation being conducted in which several different types of aircraft were designed for varying runway lengths, but to otherwise identical ground rules, in order to gain a better understanding of the merits of each type of aircraft from the point of both operator and passenger.

MCDONNELL DOUGLAS

1. American Airlines joint project (See Airlines' STOL projects)
2. Eastern Airlines joint project (See Airlines' STOL projects)
3. NASA joint project studying handling and flying qualities of various airline configurations.

RESEARCH COMPANIES & MISC. STOL PROJECTS

ANATHON, INC.

1. Market potential for STOL aircraft in the U.S. through 1985, examines the requirements for dealing with the STOL market.
2. A Computerized Systems Analysis of VTOL and STOL Air Transportation Potential in the U.S. and Canada for 1970-1985, is a comprehensive study of VTOL and STOL potential for the total U. S. market and the elements that will be required to make V/STOL a real possibility in the 70's.

PRINCETON UNIVERSITY

1. A NASA contracted study that will attempt to define the effect of wing height/span ration on lift loss due to negative aspects of ground effect on powered-lift aircraft during landings.
2. A NASA contracted study that will investigate so-called objectionable motions, on which good criteria has as yet been developed.

UNIVERSITY OF VIRGINIA

1. A joint project with NASA to make model studies of elevated STOLports in which wind tunnel investigations of building designs are incorporated into STOLports to determine wind flow patterns.

CALIFORNIA DEPARTMENT OF AERONAUTICS

1. Studied various design criteria for STOL and A/STOL ports in which the minimum dimensions for various classes of "STOLports" and "Augmented STOLports" for aircraft of less than 12,500 pounds was set forth.

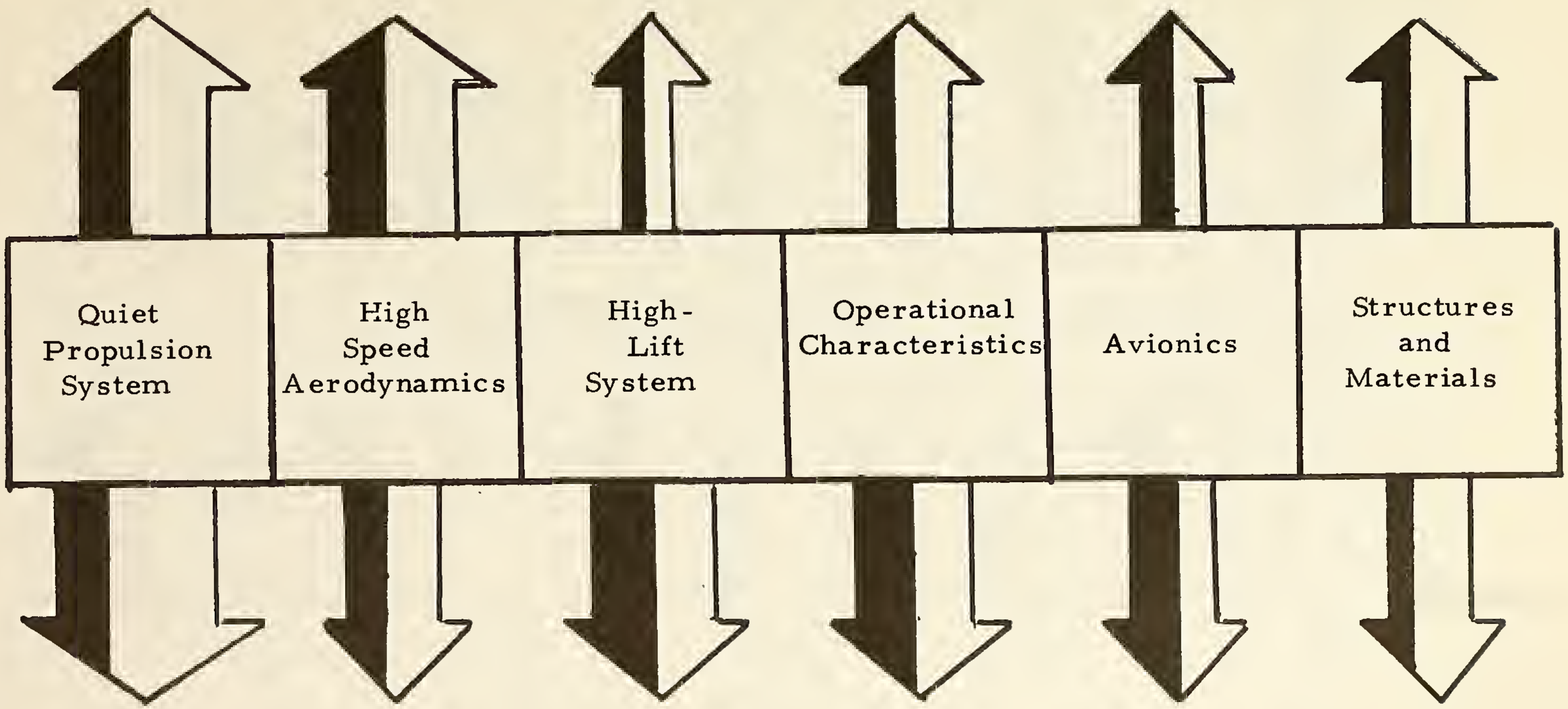
- and environmental standards are still in the research and development stage. Exhibit 3 diagramatically indicates the relative progress to date.
- The advanced technology air traffic control systems necessary to independent air space use by V/STOL aircraft includes navigation aids, special communications, data acquisition, automation and specialized landing aids. These systems are being developed but are far from their ultimate evolvement into an operational system as indicated in Exhibit 4.
- STOL airports servicing metropolitan areas present unique problems of site location, access, environmental protection, geometry and safety systems. Overall progress in these areas has been very limited as shown in Exhibit 5 . The Massachusetts Port Authority believes that STOL facilities at close-in major airports, such as Boston-Logan International Airport, can be operated as an integral part of an independent air transportation system and has included such facilities in its proposed improvement program.

3. <u>Developmental Restraints</u>

A number of basic restraints act to limit more rapid progress in

WORK REQUIRED: AIRPLANES

ADVANCED TECHNOLOGY CTOL



ADVANCED TECHNOLOGY STOL

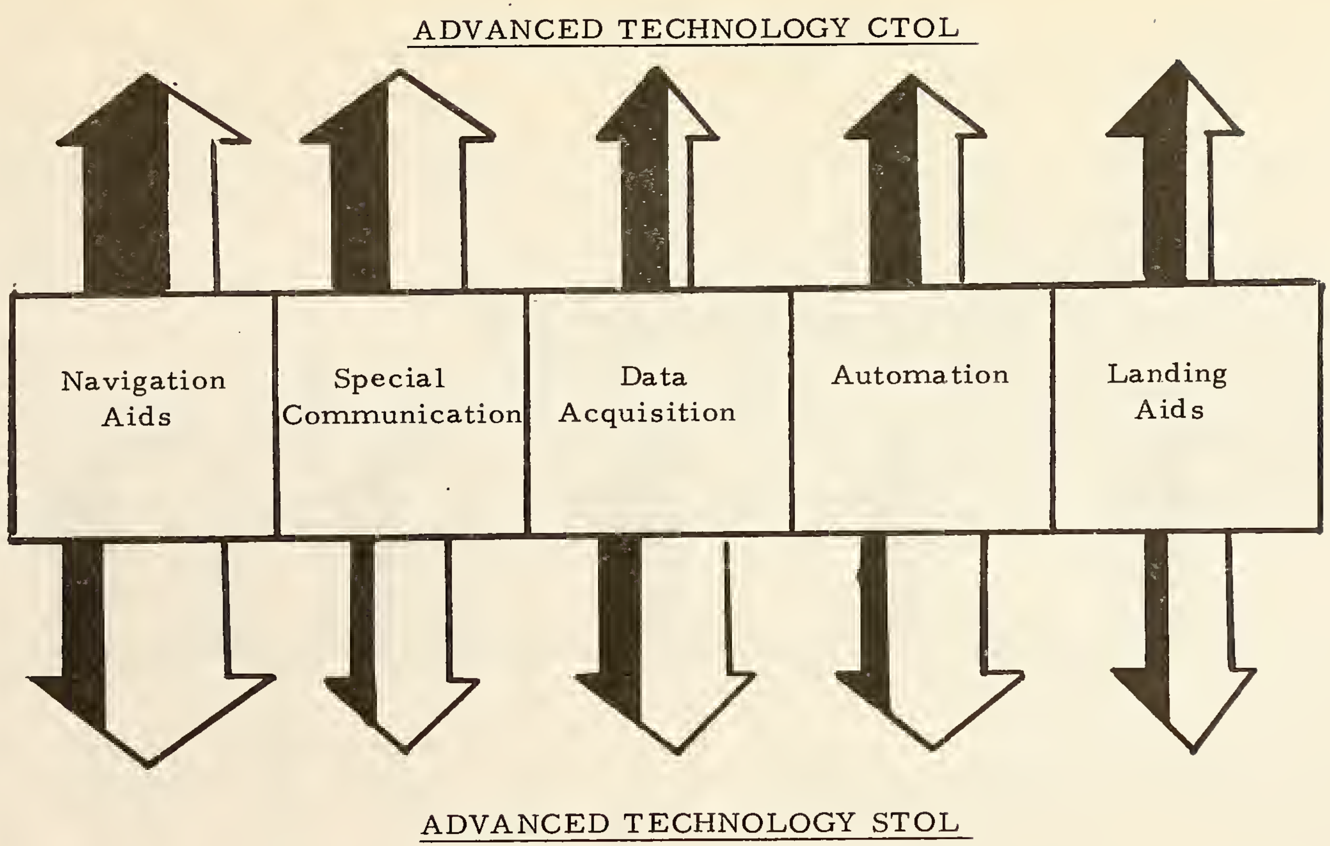
NOTE: Width of arrow indicates magnitude of problem. Shading indicates portion of work complete.

SOURCE: Boeing Aircraft Company
Seattle, Washington

DATE: May 1971

EXHIBIT 3

WORK REQUIRED: AIR TRAFFIC CONTROL SYSTEM



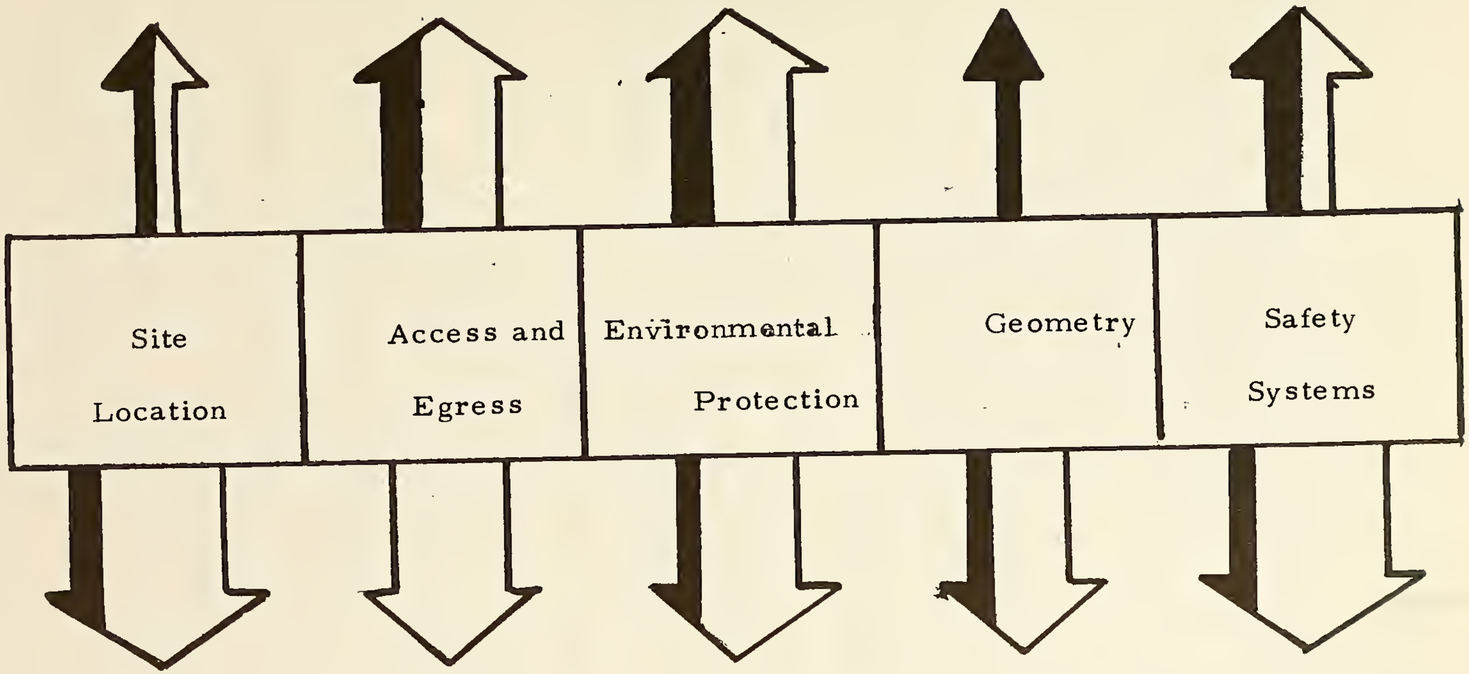
NOTE: Width of arrow indicates magnitude of problem.
Shading indicates portion of work complete.

SOURCE: Boeing Aircraft Co.
Seattle, Washington

DATE: May 1971

EXHIBIT 4

WORK REQUIRED: AIRPORTS



STOL AIRPORTS

NOTE: Width of arrow indicates magnitude of problem. Shading indicates portion of work complete.

SOURCE: BOEING AIRCRAFT COMPANY
SEATTLE, WASHINGTON

DATE: May 1971

EXHIBIT 5

the development of a V/STOL system.

a. <u>Environmental Factors</u>

- Community resistance to the selection of downtown or suburban STOLport sites on environmental grounds, principally noise.
- General environmental concern associated with the operation of turbine aircraft from any location.

b. <u>Technological Factors</u>

- Acceptable noise levels for the operation of large V/STOL aircraft from downtown or suburban STOLports must await the development of engine technologies not currently available.
- Further technological research and development is still required in other areas of air frame design, in various components of the navigational and landing aids system and in STOLport safety systems.

c. <u>Direction and Coordination</u>

- There is a significant lack of overall guidance and direction from any one central source to funnel the multiplicity of uncoordinated efforts toward a common goal.

- Basic policy decisions must be made soon and realistic time tables established if a viable system is to evolve in time to relieve saturation of major Northeast Corridor airports.

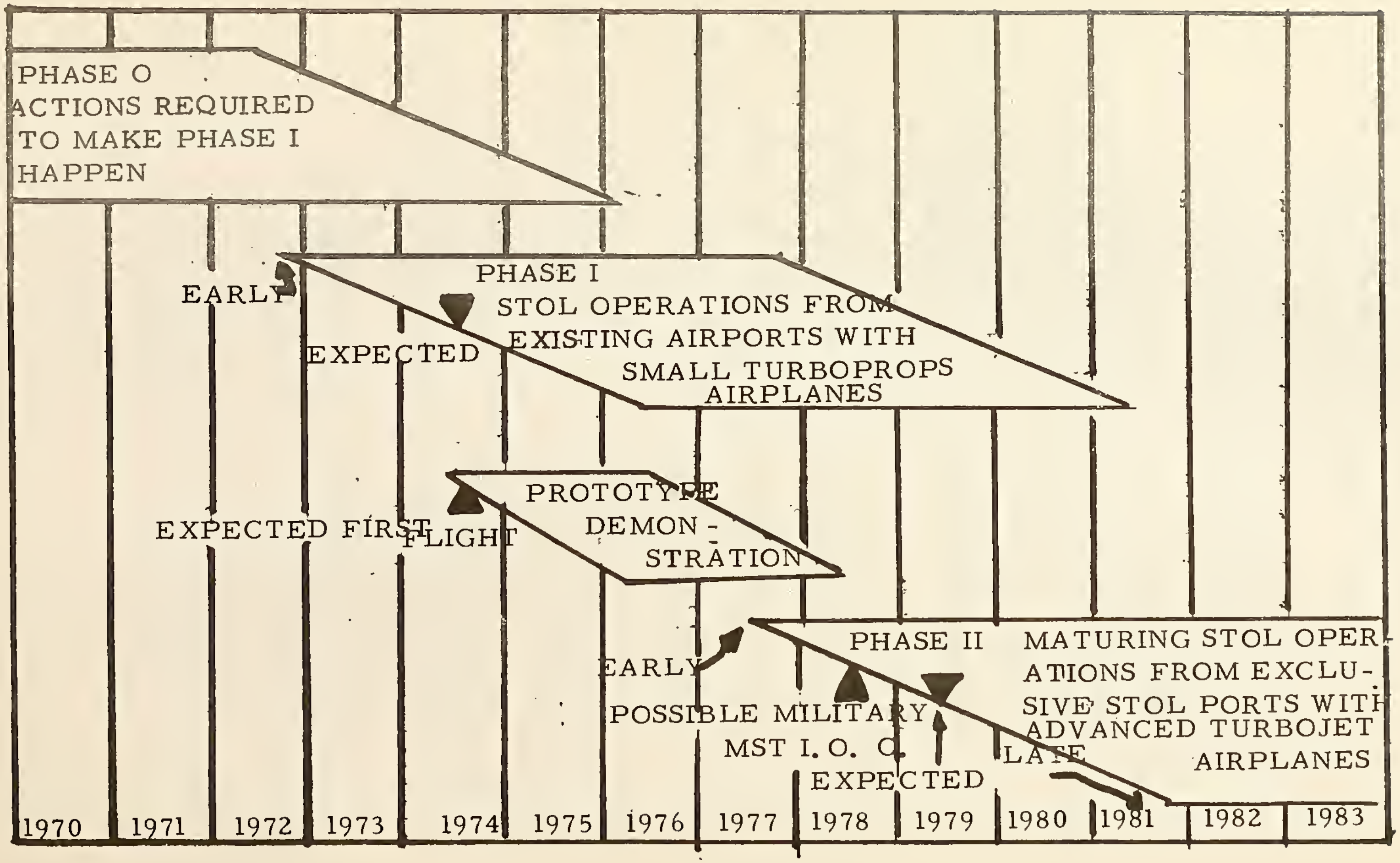
4. <u>Development Time</u>

   a. Exhibits 6 and 7 indicate in chart form tentative time tables for the NASA and Boeing STOL system programs which optimistically predict the inauguration of airline STOL service in 1979.

   b. The Massachusetts Port Authority is convinced, however, that primarily due to environmental factors and the technological problems associated with providing an environmentally acceptable V/STOL aircraft for operation from densely populated metropolitan areas, that a mass transportation system utilizing V/STOL aircraft will not be developed and in substantial competitive operation before the early 1980's, if then.

STOL SYSTEM

DEVELOPMENT PHASES

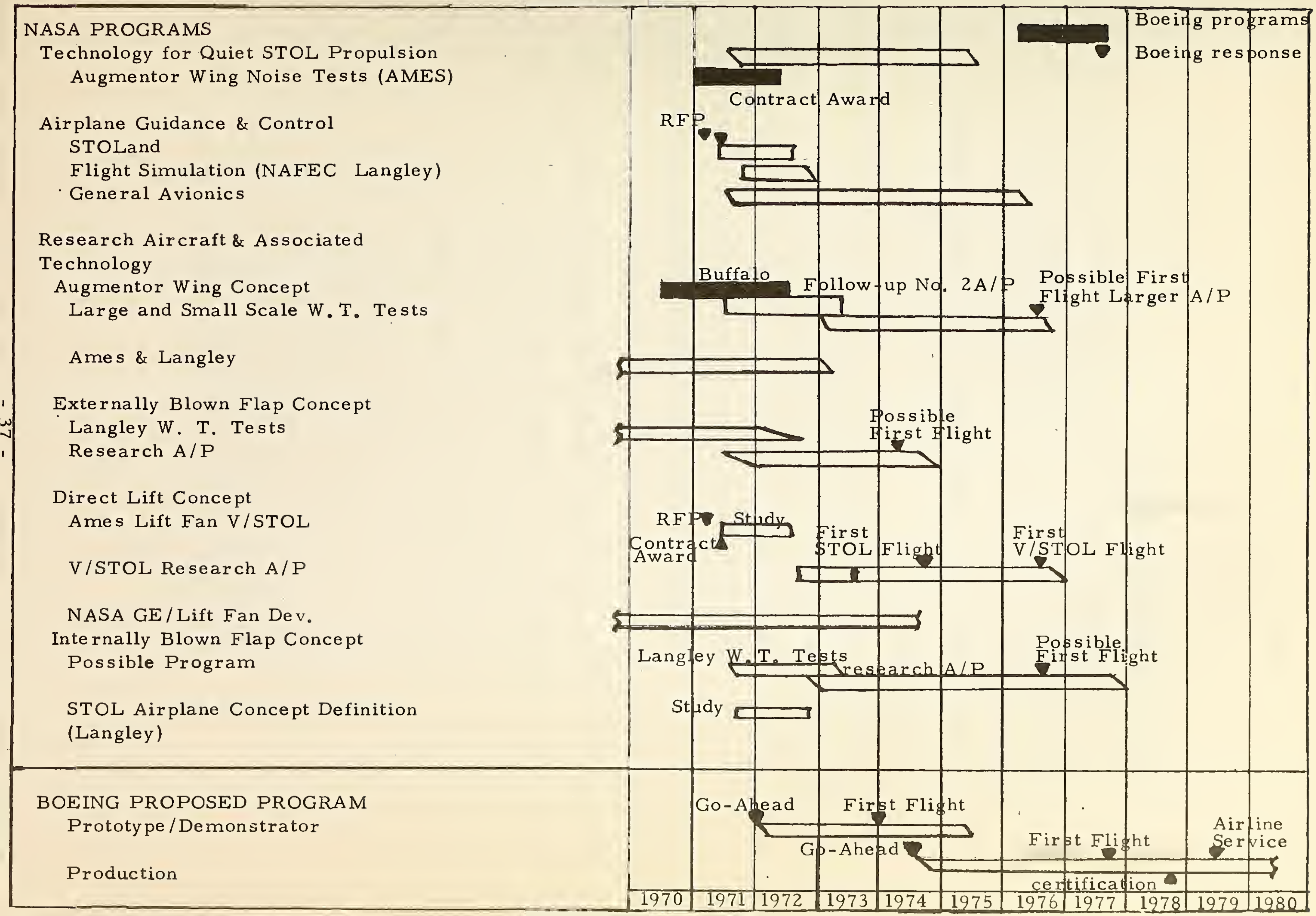


SOURCE: BOEING AIRCRAFT COMPANY
SEATTLE, WASHINGTON

DATE: May 1971

EXHIBIT 6

NASA & BOEING
STOL PROGRAMS



C. SECOND AIR CARRIER AIRPORT

An alternative often suggested to the improvement program at Boston-Logan International Airport is a second major aircarrier airport. The three most frequently mentioned sites are: Otis Air Force Base, an Off-Shore Airport and a Regional Airport between Boston and New York.

1. Prior Studies

Basic and in depth studies have been conducted relating to a second major aircarrier airport for the Boston area.

a. In 1967, the Port Authority retained the consulting firm of Landrum and Brown to assist in the preparation of a comprehensive study of the Air Transportation Potential and Facility Requirements in the Metropolitan Boston Air Service Area. This all-inclusive study examined all aspects of commercial and private air transportation facilities, their interrelationships and interdependency. Its purpose was to determine present and future adequacy of airports in the Metropolitan Boston Air Service Area and recommend improvements and additions if appropriate. Shortly after the preliminary work by Landrum and Brown began, it was determined that the Authority should join with other public agencies having the responsibility for planning and/or development of the varied transportation facilities in

the Commonwealth to insure that the most broad-based, comprehensive study and conclusions would result. The Authority joined with the Metropolitan Area Planning Council and the Massachusetts Department of Public Works by entering into an inter-agency agreement to undertake such a study.

b. Subsequently, application was made for a planning grant from the United States Department of Housing and Urban Development. This grant was received and the preliminary study was continued by the Port Authority, through Landrum and Brown, with staff assistance. This preliminary study was to be accepted by the inter-agency parties as the Port Authority's primary contribution which would serve as the foundation for the principal airport planning input to a joint study. Assisting the inter-agency group were the Federal Aviation Administration, Massachusetts Aeronautics Commission, Metropolitan Boston Transit Authority, and the Massachusetts Department of Commerce and Development. These agencies in turn formed theTechnical Advisory Committee for purposes of review and recommendation on the joint study findings.

c. The Inter-agency Committee Report on the "Boston Metropolitan Airport System 1970-1990" was published in June 1970. Among the principal conclusions relating to the need for a second aircarrier airport were the following:

- That the Authority's improvement program at Boston-Logan International Airport should be undertaken and completed.
- That with these improvements, the possibility still exists that a second major air carrier airport would be necessary by 1990 or thereafter.
- That without these improvements, the probability of a more immediate second airport requirement would be created.
- That completion of the Authority's improvement program, plus the development of a supplemental general aviation airport system, would serve as a possible alternative means of meeting the anticipated growth of both Air Carrier and General Aviation operations within the region to 1990.
- That steps should be taken to reserve an appropriate site within eastern Massachusetts for possible use as a second major air carrier airport.

d. While the Authority staff concurred with the basic findings of the Committee, it was not in complete agreement with all details, particularly the recommendation that Otis Air Force Base be given consideration as one of the alternate sites for a second major Air Carrier Airport. The reasons for this position are clearly stated in the following discussions.

2. Site Selection Requirements

Many factors must be considered in the site evaluation process for a new aircarrier airport.

a. Market Accessibility

The selected site for a new airport must be sufficiently accessible to the present and potential air traffic market in terms of travel time and distance to attract that market via such new or expanded highways and rapid transit systems as may be required. Favorable accessibility is absolutely essential to realization of the regions air commerce potential and to the development of sufficient traffic to make any airport economically feasible.

b. Airspace Compatibility

Essential to airport system planning are the criteria used to establish the air space requirements for each airport

within the system and the degree of airspace compatibility obtainable from an air traffic control standpoint.

c. Community Compatibility

This requirement is concerned with insuring minimal displacement of persons and property, and the ability to provide compatible land uses to minimize environmental impacts on the area.

d. Site Compatibility

Design requirements of the airport itself are considered and the extent to which these requirements are compatible with the physical and natural characteristics of the site selected.

e. Development Costs

Development costs, including land acquisition and necessary access facilities, must obviously be a factor heavily weighed in any site evaluation process.

3. Analysis of Suggested Sites

a. Otis Air Force Base (Cape Cod)

Otis Air Force Base adequately meets all of the site selection requirements with two major exceptions:

Development Cost

Total estimated development cost for the Otis site is as follows:

- Site Grading

17,240,000 cubic yards @ 90¢/c.y.		$15,516,000

- Land Acquisition for In-Fee Areas ---- and Improvements

Lump sum (estimated)		16,681,000

- Airfield/Runway, Taxiway Paving

Lump sum		20,000,000

- Terminal Areas, including buildings — 160,000,000

- Utilities, Roadways, Drainage

Lump sum		100,000,000

- Primary Access Highways

50 miles @ $7,834,700/mile	$391,735,000	
Land acquisition 24,000 acres @ $4,000/acre	9,600,000	401,335,000

Number of persons affected: 3,168

- Rapid Transit

50 miles @ $6 million/mile (including Bridge over canal)		340,000,000
		$1,053,532,000

Development costs of this magnitude could not be justified on any basis for a non-tax supported facility.

Market Accessibility

- Otis Air Force Base is located approximately 67 miles from Downtown Boston, 88 miles from Worcester and 62 miles from Providence. Due to its remote location from the principal Boston market, a new limited access highway would be required as well as a 50 mile rapid transit extension.

Even with these new access facilities, however, the site is considered far too remote to be even marginally acceptable from the market accessibility standpoint. In the selection of any site for a second aircarrier airport, the vital importance of its location with respect to market accessibility is a factor which cannot be emphasized strongly enough. Although all other factors affecting site acceptability must also be met to a reasonable degree, it is imperative that the site be sufficiently accessible to the market to insure that adequate market potential will be realized. It is of paramount concern that the major concentration of population in need of air transportation services will actually use the airport, if constructed. Otherwise, there can be no need for an airport in that location, regardless of how desirable it may be in every other respect. If not used to a significant degree, there can be no basis for financing the

development through user charges. This could only result in what is considered to be the unacceptable alternative of placing the burden for development on the Massachusetts taxpayer. Irrespective of this, it is also plainly evident that any site which does not attract sufficient volumes of traffic to significantly decrease the air carrier demand upon Logan would completely defeat the basic purpose of establishing a second aircarrier airport in the first place. Boston-Logan International Airport would continue to be saturated, unable to meet the air service requirements of the Metropolitan Boston area, and a tremendous investment would have been made without a substantial relief from the very problem for which it was expended.

b. Off-Shore Site (Brewster Islands)

The Brewster Island site does not meet three of the five necessary site selection requirements and the remaining two are questionable.

- Market Accessibility

  - While the Brewster Islands are only approximately six miles further out in the harbor than Boston-Logan International Airport, the only existing access would be by boat or aircraft. The requirement for ground transportation access from the Metropolitan Boston market areas is obvious but would require tunnels, bridges, elevated causeways or combinations of these

facilities to adequately serve the site and minimize conflict with maritime and recreational interests. These facilities would most likely be constructed from landfalls in the Neponset area to the south and Point Shirley or Nahant to the north.

- The possibility of shuttle air links and/or high speed shuttle boats, in lieu of ground access, would seriously limit market potential which might otherwise be realized.

- It has been suggested that only terminal facilities be utilized at Boston-Logan with all aircarrier operations conducted at the Brewster Island Airport which would have only limited facilities of this type. This would not only necessitate an intermediate form of connecting transportation over an extended distance, adversely affecting Brewster's market potential, but would completely negate the reason for building a second aircarrier airport in the first place; namely, greatly increased overall capacity to meet the air service demands of the Metropolitan Boston region.

<u>Air Space Compatibility</u>

- A second major aircarrier airport on the Brewster Islands could not be operated simultaneously with Boston-Logan International Airport since there would be almost total airspace conflict. See Exhibit 8.

METROPOLITAN BOSTON
BOSTON-LOGAN AND BREWSTER ISLAND SITE
AIRSPACE CONFLICT AREA

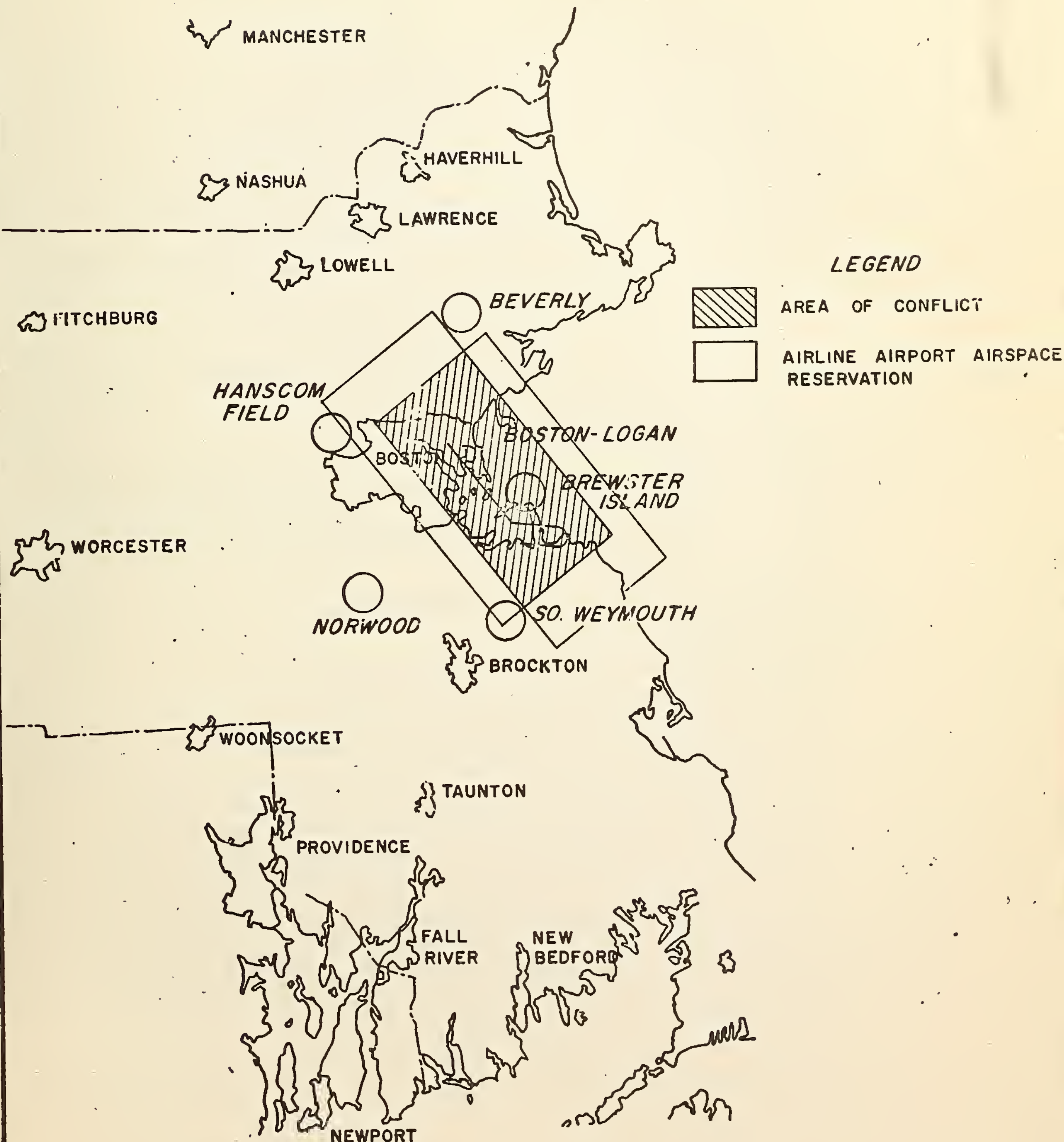


EXHIBIT 8

- Were the Brewster Island site to become the only aircarrier airport in the Boston service area due to this conflict, air service demands of this region could not be met.

- Community Compatibility

  - Preliminary studies indicate that the communities of Hull, Nantasket, and North Weymouth would become aircraft noise exposure areas (whereas they are presently unaffected) under a Brewster Island 4-22 runway orientation which should be provided in accordance with established meteorological wind rose selection criteria.
  - The MAPC Open Space and Recreation Plan for Boston Harbor now earmarks the Brewster Island Chain for recreation use in the near future.

- Site Compatibility

  - It is questionable whether there is sufficient land and water area available for the development of a scheduled airline airport meeting the 5,000 acre criterion used in these studies without interfering with other land and water oriented uses.
  - The airport itself and the necessary access facilities to serve it would create conflicts with water navigation and shipping interests.

- Development Cost

  - Site development costs would in themselves be prohibitive. Conventional dike and earthfill construction, which is the only feasible method, would cost an estimated 1.25 billion dollars at $250,000 per acre plus the additional expense of special shoreline protection in the less protected outer harbor. Based upon current costs for similar construction, this would be a conservative estimate.
  - Airport facilities would add at least 200 million dollars more.
  - The costs of the tunnels, bridges, causeways and connecting highways have not even been estimated but could well exceed an additional one half billion dollars.
  - A total project cost on the order of 2 billion dollars is not unrealistic. Such an expenditure could not possibly be justified on any reasonable basis since the investment could never be financed by user charges and massive tax support would be necessary. (An investment of 2 billion dollars would require an annual debt service of over 130 million dollars as compared with total annual Port Authority revenues of approximately 27 million, much of which is committed to debt service on bonds already outstanding.)

c. <u>Regional Airport</u> (Eastern Connecticut)

- The Interagency Technical Advisory Committee reviewed an alternative recommendation contained in a state of Connecticut Airport Consultant Study (1) that consideration be given to the location of a major air carrier airport in the Southeastern section of that state at the Rhode Island boundary. This area is approximately 70 miles from downtown Boston. In view of the uncertain status of the attitude of the State of Connecticut toward the airport proposal, and in view of the great distance between this proposed site and the Boston air passenger market area, the Technical Committee concluded that no serious consideration could be given to this site at this time.
- Although site selection requirements have not been studied in detail by the Authority, the very remote location of this site from Metropolitan Boston's market area, its inability to divert adequate traffic from Logan and the extensive highway and rapid transit facilities which would be required to serve it, equates it closely to the Otis Air Force Base site evaluated earlier. The same basic conclusions apply, it being if anything, an even less acceptable alternative which would have to rely heavily on tax revenues.
- This alternative involves, in addition, complex political considerations due to the multi-state nature of the project, particularly if it were designed to become a reliever airport for Rhode Island and New York areas as well.

(1) Airport Facilities Plan for the State of Connecticut, Frederic R. Harris Associates, April 1969

3. Summary

a. None of the second major aircarrier airport sites analyzed above even marginally meet overall site selection requirements. It is emphasized again that the site for a second aircarrier airport, when and if it becomes necessary, must be located sufficiently close to the major air passenger market which it will serve to insure that adequate traffic will be generated to support its development, as well as to provide the necessary capacity relief which prompted that development. Until such time as a second major aircarrier airport may come into being, Boston-Logan International Airport must meet the air service demands placed upon it by the Metropolitan Boston region.

b. A careful balance must be struck between the various basic site selection criteria which tend to counter-oppose one another, since land availability and compatibility of use have a tendency to be more easily obtainable in areas remote from market demand. On the other hand, it logically follows that locations close to the markets have limited land availability and possibilities for compatible land use become more difficult to achieve. It must be concluded, therefore, that unless this fine balance can be achieved, there can be no real solution.

D. TRANSFER OF INTERNATIONAL TRAFFIC TO AN ALTERNATE SITE

1. It has been frequently suggested that the need for capacity at Logan, as well as runway length requirements, could be substantially diminished if international

air service were transferred to a remote airport site; for example, one of several military air bases each sixty miles or more from Boston. It is acknowledged that the excessive distance to such remote locations become less critical as the length of the air trip increases. It is also conceivable that a one and a half hour drive to the airport for the European bound passenger would not discourage a significant number of potential passengers from making the trip. The fallacy in this reasoning lies in several areas:

a. A major portion of international traffic is, in fact, short haul. Service to principal cities in Canada and Bermuda, which constitutes nearly 70% of the total international traffic, ranges only between one and two hours in flight time and is operated with aircraft that are small enough to serve the short and medium haul domestic routes.

b. The runway length necessary for international flights is little different than for the longer haul domestic flights. To eliminate them from Boston-Logan would have no significant impact on runway length requirements.

c. International long haul flights constitute a relatively minor portion of total aircraft operations and operate principally at off-peak periods in relation to domestic air service. To relocate these long-haul flights to another airport remote from the market would prove of little value in making significant additional capacity available at Boston-Logan for the shorter haul domestic flights.

d. Also very significant, is the fact that international service through the Boston Gateway must be supplemented by connecting traffic to and from other cities within the United States. Without this supplemental traffic from other areas, the airlines would be unable to support the broader pattern of European service now available. This will become increasingly true with the greater capacity aircraft such as the Boeing 747. The Boston market itself can support service only to the strongest route segments such as Boston-London. It therefore becomes extremely important that convenient and frequent connecting service be provided between the international gateway and principal Untied States cities. However, with international air service from Boston operating exclusively from a separate and remote airport, the limited international market could not conceivably support adequate domestic connecting service for this purpose alone. Lacking this frequent and convenient domestic connecting service, the majority of the potential market through the Boston Gateway would be lost to other competing Gateways, and transatlantic service from Boston would degenerate to a level and pattern of service which could be supported by the Metropolitan Boston market only. Since transatlantic schedules would then serve very few European points and on an infrequent basis, transatlantic passengers would utilize domestic connecting service to other international gateways which did provide the service desired. The effect would be to increase air traffic demands

on Boston-Logan International Airport, the very effect which the transfer of international operations was designed to avoid.

2. For the reasons described, it is unrealistic to assume that the capacity problem that will occur at Boston-Logan International Airport in the future can be realistically or significantly helped through a transfer of international air service from that facility to a remote international gateway airport and that to do so would only serve to degrade international air service through the Boston Gateway.

E. FARE AND LANDING FEE DIFFERENTIALS

Another proposed alternative to the improved program involves the establishment of fare and landing fee differentials designed to encourage the spreading of peak hour operations into off-peak hours and thereby to increase airport capacity. The fallacy of this reasoning falls into three basic categories.

1. Inadequate Economic Inducement

As was the case with the proposal for a landing fee surcharge to encourage the use of quieter aircraft, there is insufficient economic leverage in the landing fee to induce the airlines to reschedule flights away from peak periods of passenger demand. As for fare differentials, domestic airline passenger fares are regulated by and under the exclusive purview of the Civil Aeronautics Board, while international fares are controlled by the International Air Transport Association. As such, they are totally outside of Port Authority jurisdiction and control.

a. Landing fees at Logan only represent approximately 1% of total airline expenses incurred as a result of operating from that facility.

b. Revenue losses from reduced load factors, resulting from scheduling flights during off-peak demand periods, would offset by a wide margin the savings in landing fees realized.

c. Aircraft delays, which increase as peak hour capacity is approached and then exceeded, act in themselves to spread the peaks as delay costs become prohibitive and exceed anticipated load factor losses from off-peak scheduling.

2. Factors Which Create Peaking

A number of factors operate within the air transportation system which create peaks in air traffic during certain hours at airports within the system.

a. Passenger demand for service at certain desirable travel hours. This impact is particularly strong for "same day" business travel in the shorter haul markets.

b. Time zone differentials and their effect upon desirable arrival and/or departure times in the longer haul markets.

c. Originating aircraft departures each morning and terminating aircraft arrivals each evening after a full day's utilization on system routes.

d. The complexities of airline scheduling over their entire route structures, the dependency of each schedule on many others and the chain reaction effect which rescheduling at one point can have on schedules throughout the airport system.

e. In simplified form, the factors which create traffic peaks in the airline industry are little different than those which create traffic peaks in any other mode of transportation. If office hours were staggered throughout the day, for example, rush hour traffic peaks would become non-existant and highway congestion problems would be essentially eliminated. Obviously, however, this is not a feasible or practical solution since automobile travel, like any other form of transportation, is directly tied to the life style of our population and to the travel needs which it dictates.

3. Results of Peak Spreading

a. Even were it possible to completely level traffic peaks, little overall capacity would be gained between the hours of 7 A.M. and 10 P.M. because hourly demand does not vary significantly. Only by spreading operations into the nighttime hours could significant capacity increases be realized.

b. While peak spreading will result in some capacity increases, a full leveling is not practically attainable and limits the capacity increases which are realistically possible.

c. Were peak spreading forced upon the airlines at Boston, it could adversely affect air service. Since Boston-Logan International Airport is principally an originating and terminating point, the Airlines would tend to cut Boston air service rather than to upset schedules throughout their route systems.

F. MORATORIUM ON AIRFIELD AND TERMINAL IMPROVEMENTS

It has been proposed that a moritorium be imposed on all construction projects at Boston-Logan International Airport, including airfield improvements as well as terminal area improvements, until such time as all alternatives to the future transportation needs of the Boston area are thoroughly explored and the best means of meeting those needs are determined. This proposal will be discussed in terms of its air service, environmental, legal and economic implications.

1. Air Service Implications

a. The detrimental effects of delaying airfield improvements upon air service and aircraft delays is fully documented in the Consultants' Report.

b. The impact of a moratorium on terminal area improvements would include:

- Loss of air service resulting from the competitive disadvantage of Airlines without improved facilities and lack of facilities to attract new service.

- Increasing gate delays and inadequacy of gate positions, particularly in the South and International Terminal areas.
- Inconvenience, delay and overcrowding borne by the airline passenger.
- Handling and air shipment delays of cargo and mail.

2. Environmental Implications

The detrimental environmental effects of delaying airfield improvements, in terms of noise and air pollution in particular, are fully documented in the Consultants' Report.

3. Legal Implications

Under the provisions of the Authority's Enabling Act it is charged with the responsibility of extending, enlarging, improving, rehabilitating and operating the projects under its control. Logan Airport being one of these, a self-imposed moratorium on improvements to that facility would violate the provisions of the Enabling Act and thus preclude it from taking such action. The Authority is also bound by a Trust Agreement which constitutes a contract between the Authority and its trustee, under which all Authority bonds have been sold. This agreement contemplates and requires the continued improvement and operation of the Authority's projects. It appears quite clear that legislative action to impose a moratorium would constitute legislative interference with a private contract and would therefore be unconstitutional.

4. <u>Economic Implications</u>

a. An estimated total of 1900 construction jobs would be lost with a payroll approaching 20 million dollars.

b. Were a moratorium to be imposed on all improvements at Logan, the Massachusetts Port Authority would involuntarily abridge contracts and agreements totaling approximately 120 million dollars and incur investment losses of over 25 million dollars in addition.

- Contracts and agreements which would be abridged:

- South Terminal development and lease agreement with airlines	$90,000,000
- International Terminal design agreement with airlines	1,600,000
- Landing area agreement with airlines (partially completed projects)	12,912,500
- Interim South Terminal agreement	7,000,000
- Runway dike and drainage (bid received)	7,625,000
- Agreement with FAA for relocation of navigational aids	300,000

- Loss of investment:

- Control Tower (under contract)	$6,000,000
- Runway phase 1 & 2 design (completed)	262,500
- Taxiway relocation (completed)	4,500,000
- Expansion of utilities (completed)	4,093,000

- Relocation of navigational aids (partially completed)	800,000
- Apron construction (complete)	1,350,000
- International terminal design (expended)	900,000
- South Terminal (design and interim construction completed)	7,000,000

c. Immediate and direct loss of investment noted above and potential loss for breach of contracts.

d. Reduced revenues derived from facilities completed to date.

e. Loss of promotional investment to gain increased air service and develop the Boston International Gateway.

f. Overall adverse effect upon the economy, both direct and indirect.

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SECTION III

AIRPORT ACCESS ANALYSIS

This section of the staff study represents an analysis and report by Joseph M. Manning, President of Urban Transportation Systems Associates with Massachusetts Port Authority Staff Assistance.

SECTION III

AIRPORT ACCESS ANALYSIS

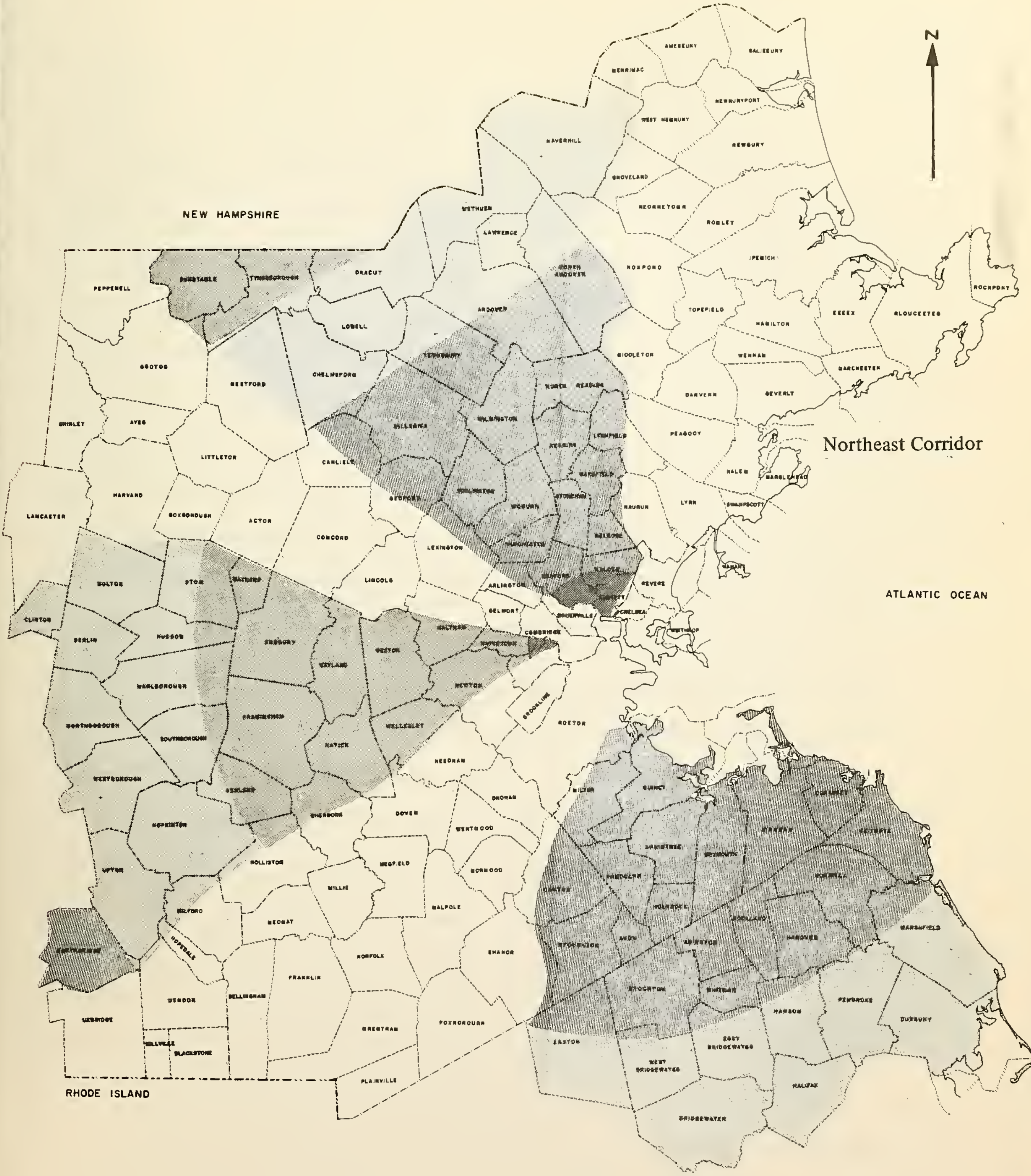
A. THE REGION AND THE NORTHEAST CORRIDOR

Logan Airport is situated at the base of the Northeast Corridor of the Eastern Massachusetts Region. (See Exhibit 9) This corridor extends from Boston in the south, north to the New Hampshire line. It covers 30* cities and towns with a total population of 590,680 persons in 1963 and 631,000 in 1970. Below is a Table from the Eastern Massachusetts Regional Planning Project report "Recommended Highway and Transit Plan" which gives some highlights about the corridor.

NORTHEAST CORRIDOR HIGHLIGHTS

	1963	1990
Population	590,680	756,316 - 758,387
Employment	173,714	248,351 - 250,394
Automobile Ownership	178,152	342,192 - 342,412
Total Person Trips	1,169,108	1,598,352 - 1,610,641
Person Trips to Boston Core	52,338	66,188 - 68,050
Total Transit Person Trips	91,679	92,785 - 125,553
Transit Person Trips to Boston Core	25,589	26,459 - 27,705
Total Highway Vehicle Trips	862,872	1,236,042 - 1,240,421
Highway Vehicle Trips to Boston Core	22,896	35,617 - 36,760

* Not including Boston and Chelsea



RADIAL AND CIRCUMFERENTIAL TRANSPORTATION CORRIDORS
EASTERN MASSACHUSETTS REGIONAL PLANNING PROJECT

EXHIBIT 9

Expected population growth in the corridor averages out to about 1% per year for the next two decades. The corridor holds about 17% of all the region's population and 13.3% of the total regional employment. About half of the Northeast Corridor's population is concentrated in the key cities of Lynn, Peabody, Revere, Salem, Beverly and Gloucester. The Northeast Corridor area is a mixture of residential suburbs and employment concentrations. Rockport and Marblehead have fine seashore homes, while Lynn and Peabody have concentrations of industry, such as the General Electric complex. This diverse corridor which contains so much action and so many people has, as a result of its diversity and widespread activity centers, many transportation problems. Its highways, streets, and rail transit facilities are in many cases old and overloaded. From the Mystic River Bridge and Sumner-Callahan Tunnel in the south to I-95 and Route 1 in the north, these problems are being examined and plans developed to resolve them. The next section reviews those plans and problems.

B. TRANSPORTATION PLANS AND PROBLEMS IN THE NORTHEAST CORRIDOR

The Recommended Highway and Transit Plan of the Eastern Massachusetts Regional Planning Project forms the basic starting point for the Boston Transportation Planning Review. The problems in the Northeast Corridor are representative of those throughout the region. They include the congestion on city streets, the lack of transit service, the disruption and dislocation a major expressway construction project can cause and the need to enlist community understanding and support for transportation projects designed to benefit the region. These kinds of problems cannot be solved at the community or agency level of government, rather it will take a Federal-State team effort with Legislative, community and agency coordination and consultation throughout the process to arrive at solutions and

plans which can be implemented. Because the Boston Transportation Planning Review has identified the Recommended Highway and Transit Plan as a benchmark, it will be used in this analysis of plans and problems.

The Recommended Highway and Transit Plan report contained a detailed analysis of two of its four alternative regional plans. These two alternative development plans assumed the same 1975 highway and transit network, but for 1990 there are two different highway and transit networks. Plan A (Composite Plan) relied more heavily on transit to accomplish its higher density development objective, while Plan C (Controlled Dispersal Plan) relied heavily on highways to accomplish a more dispersed land development objective.

The principal radial expressway serving the Northeast Corridor is Interstate Route 95. Rapid transit service is provided by the Blue Line to Wonderland in Revere. In addition, the MBTA provides bus service to 14 communities in this sector. North Shore communities are also served by railroad commuter service under the contract between the MBTA and the B & M.

HIGHWAY

Interstate Route 95: The forecast average daily travel on I-95 between Salisbury and Route 128 can be adequately served by the existing and proposed facility in both plans. The I-95 volumes in Plan A reach a maximum of 76,000 vehicles per day just north of Route 128. Plan C volumes reach 64,000 vehicles per day at the same point. There are differences of about 15,000 vehicles per day on some sections of I-95 because the Middle Circumferential does not connect with I-95 in Plan A.

The existing section of I-95 north of Danvers was built before the Interstate Highway Program was begun and does not conform to present Interstate Design Standards for speed, approach ramps, median width, and

alignment. During summer weekend peak-travel periods, this portion of I-95 experiences severe congestion over its entire length. For these reasons, I-95 from Danvers to New Hampshire is undergoing widening, which is near completion.

Construction of I-95 between Danvers and Revere is presently stopped due to the highway construction moratorium. Projections of future traffic indicate that as many as 145,000 vehicles per day will be carried on I-95 between Route 128 and the Beverly-Salem Connector. Factors contributing to this sizable traffic volume are the inclusion in the network of a New Harbor Crossing and the Connector to Beverly and Salem. The high volume of traffic turning on and off I-95 at Route 128 and at the Connector will cause critical weaving problems on I-95 in this section unless some relief is provided.

A possible alternative to relieve I-95 is the improvement and possible relocation of Route 114 to meet the Beverly branch of the Beverly-Salem Connector. The travel desire for this movement was not expected to be as sizable as developed; therefore, this improvement was not contemplated in the alternative networks. An upgraded Route 114 from North Andover to Route 1 was included in Plan C, and was extended to Route 128 in Plan A, but indications are that the upgrading should have been continued to the Beverly branch of the Connector. This improvement would alleviate the I-95 weaving problem by furnishing a suitable alternate route to Salem and Swampscott from the north and west.

Also Route 1, which is forecast to carry only moderate traffic between Route 128 and Cutler Circle in Revere, could serve as an alternative route to Cutler Circle and the Northeast Expressway if peak-period congestion begins to occur on I-95.

I-95 from Cutler Circle to the Chelsea approach to the Tobin Bridge (formerly the Mystic River Bridge) was built before the start of the

Interstate Highway Program and is substandard according to Interstate Design Standards. Raising this section of roadway to Interstate Standards, however, would be virtually impossible on the present alignment and would elevate the cost of improvement to an unjustified amount. Less costly improvements, such as the addition of acceleration and deceleration lanes designed to meet higher standards, better gradients on some approach ramps, and partial reconstruction of the I-95/Revere Beach Parkway interchange, would substantially increase the safety of this roadway.

I-95 in Charlestown between the Tobin Bridge and the Storrow Drive exit ramps from the Central Artery is presently a source of frustration to peak-period motorists. Severe congestion also occurs in the Sumner and Callahan Tunnels, as commuters frequently face long lines of stopped traffic stretching the length of the tunnel. It is clear that major harbor crossing improvements are needed to handle today's traffic satisfactorily, let alone the increases projected to occur by 1990.

New Harbor Crossing: Traffic using the Tobin Bridge and the Sumner and Callahan Tunnels currently amounts to approximately 138,000 vehicles per day. Improvement of the approach facilities and elimination of restrictions would allow a total flow of about 160,000 vehicles per day (100,000 on the Tobin Bridge and 60,000 in the Sumner and Callahan Tunnels) at the lowest acceptable level of service.

The daily crossings of the Boston Harbor and Mystic River in 1990 will amount to approximately 186,000 vehicles without a New Harbor Crossing, according to new forecasts, and 203,000 vehicles with a New Harbor Crossing, according to forecasts made by a consultant for the Massachusetts Turnpike Authority. Based on the overload on present facilities by 1990 of

26,000 to 43,000 daily trips, a New Harbor Crossing would be necessary some time after 1975. Unless another harbor crossing is included in the future expressway system, additional capacity will have to be provided on the bridge or the tunnels and improvements will have to be made to the Central Artery in addition to those already anticipated.

Shore Expressway: A New Harbor Crossing is not a complete solution without other improvements. The new crossing would carry 72,000 vehicles per day by 1990 and would provide sufficient capacity for all forecast traffic. On the north side of the water, however, complications arise. Both this new crossing and the Sumner and Callahan Tunnels funnel traffic onto Route C-1, which is projected to carry 100,000 vehicles per day just north of Boston-Logan International Airport and over 70,000 vehicles per day near Bell Circle in Revere. Between Bell Circle and I-95[(1)] in Saugus, the average volume forecast for Routes C-1 and 107 is 58,000 vehicles per day. To accommodate these volumes adequately and provide system continuity, a Shore Expressway should connect the New Harbor Crossing with I-95 in Saugus. The construction of an expressway and New Harbor Crossing between I-95 in Saugus and the Inner Belt near South Station would eliminate the need to increase the capacity of the existing Northeast Expressway, Tobin Bridge, and Sumner and Callahan Tunnels.

Of major importance is the excellent access that the Shore Expressway would provide to the regions's principal airport. Boston-Logan International Airport is a significant factor in the growth of the region, because of its accessibility from the central city and the surrounding area. For the airport to continue to serve the region adequately, it must be easily accessible. The New Harbor Crossing and Shore Expressway would perform this vital function in addition to accommodating the increased number of harbor

(1) Shore Expressway - Relocated I-95

crossings for other purposes.

Beverly-Salem Connector: The construction of the Beverly-Salem Connector from I-95 in Peabody will provide expressway service to additional communities on the North Shore. In Salem, the Connector branches northeast to Beverly and southeast to the Salem-Swampscott town line. The location of the Connector is the same in Plans A and C. The existing Beverly Harbor Bridge will be replaced by the new facility, which will carry 25,000 vehicles per day, thus helping to relieve peak-period congestion.

The Beverly branch of the Connector carries a maximum of 40,000 vehicles per day in Plan A and 32,000 vehicles per day in Plan C. Without the Beverly branch, travel from north of the harbor toward Boston would use Route 128 in the Peabody, Danvers, and Beverly sections to reach I-95. The Beverly branch will give residents in this area high-speed access to I-95, thereby preventing an increase in travel east of I-95 on Route 128, which carries a heavy volume even with the Connector in the network.

The Salem-Swampscott branch carries a maximum volume of 61,000 vehicles per day in Plan A and 54,000 vehicles per day in Plan C. The volume on the Connector between the fork and I-95 is 71,000 vehicles per day in Plan A and 76,000 vehicles per day in Plan C.

This area of the North Shore does not have other roadways capable of serving an additional 25,000 to 76,000 daily trips. Routes 1A, 107, and 114 are already congested during peak periods and could not handle the added load. The Connector would provide excellent service to the communities of Salem, Swampscott, Marblehead, and Beverly. It would provide an express routing around the business areas and connect with expressways leading in all directions. The cities of Lynn and Revere will directly benefit from relief of the traffic, which will make Routes 107 and 1A more usable for local requirements.

The volumes assigned to the Connector are sufficiently high to justify an expressway facility, and no other reasonable alternative would provide the needed relief to Route 107, which is badly congested during peak periods at the present time.

Revere Beach Connector: The Department of Public Works has considered a roadway from Cutler Circle to Revere Beach to relieve the arterials in the Northeast Corridor. This Connector is a recent proposal of the Department of Public Works and was not tested in the alternative networks. It appears that such a facility would not only serve recreational traffic, but would relieve certain arterial roadways in the area.

TRANSIT

Blue Line: Under Plan C, North Shore transit service is essentially the same as today, while under Plan A the Blue Line rapid transit service is extended from Wonderland to Route 128 in North Beverly. An express operation would bypass all stations between the existing Airport Station and Revere Marshes. The Suffolk Downs station would become seasonal, operating only during the racing season at the Suffolk Downs racetrack.

Available parking at the existing Wonderland terminal of the Blue Line is now limited to approximately 500 spaces, and it is estimated that by 1990 the demand will increase to approximately 3000 spaces without an extension of the line. In addition to relieving this potential traffic and parking problem at Wonderland Station, an extension to a point just beyond Route 128 in Beverly would attract an estimated 18,000 riders, increasing the number of daily passengers carried at the peak-load point from 62,000 to 80,000. However, if the rapid transit line is not extended beyond Wonderland, some of the forecast park-ride transit trips would be lost because of insufficient parking and would become highway trips to downtown Boston instead.

Recently, the MBTA studied the engineering feasibility of extending the Blue Line from Wonderland to a new terminal in the vicinity of Route 107 and the Pines River; or Vinnin Square, Salem; or Route 128 in Beverly. A short extension to the vicinity of the Pines River appears to be justified as part of the short-range transit program to provide the necessary additional parking capacity. The terminal must include a large parking lot accessible primarily from I-95 and Route 107 and must allow for the further extension of rapid transit to the north as part of the long-range program.

Essential to the viability of the Blue Line transit extension is better downtown distribution. This can be most effectively accomplished by a subway link in downtown Boston connecting the Blue Line with a rapid transit line in the Western Corridor. The feasibility of this link is being examined in the MBTA's Central Area System Study. A short branch extension into the Logan Airport terminal complex to permit direct rapid transit service from downtown to the terminal building was studied by the MBTA in cooperation with the Massachusetts Port Authority, but deemed infeasible from both a cost/benefit and an operational standpoint.

With the provision of better downtown distribution, a rapid transit extension would divert more people from the highways than either railroad or express bus service. With through service downtown and better airport access, which were not tested in the alternate plans, the number of additional riders carried on the Blue Line should substantially exceed the 18,000 forecast for Plan A.

Beyond 1975, the problems associated with reducing costs, changing union work rules, providing adequate equipment, operating over a right-of-way harmoniously with freight service, and improving downtown distribution are so severe that the alternative of providing transit service to the North Shore by a combination of a rapid transit extension and integrated bus

service may be required. The potential increase over the Plan A forecast that results from better downtown distribution and Western Corridor through service, together with the infeasibility of providing the required number of parking spaces without an extension, indicates that a rapid transit line to the vicinity of the Salem Connector would be the most practical solution to the long-range transit requirements for the Northeast Corridor.

Assuming that future studies substantiate the need for the extension described, the station locations and parking space estimates for the Blue Line would be as follow:

Station		Parking Spaces
Maverick		0
Airport		100
Wood Island		500
Orient Heights		260
Suffolk Downs		120
Beachmont		210
Revere Beach		180
Wonderland		480
Pines River		2500-3500
Lynn		0
Swampscott		100
Salem Connector		1000-2000
	Total	5450-7450

In conjunction with the Blue Line extention, Plan A tests an express transit track from Pines River to Airport Station that would bypass the intermediate stations. The additional riding attracted because of the time saved by such a bypass does not appear sufficient to justify its construction in conjunction with an extension to the Salem Connector.

Another option for providing through rail transit service between the North Shore and Western Corridors would be by a new rail transit harbor crossing built in conjunction with the new highway harbor crossing. This

crossing would permit the use of wider, longer transit cars than the present limited-diameter transit tunnel under the harbor would allow. It would, however, have the serious disadvantage of bypassing many major transit trip generators in the downtown area, such as the redeveloped waterfront, the financial district, Government Center, and the retail core.

If the increased ridership that would be generated by better downtown distribution is not adequate to justify the cost of the required service and facilities, the Blue Line should not be extended beyond Pines River. In this event, the long-range transit service would probably be greater use of express buses. One alternative would be to have these buses feed the rapid transit terminal at Pines River. Another would be to run the buses directly into downtown Boston via the New Harbor Crossing to a new bus terminal at South Station.

SUMMATION

A summary of committed projects and recommendations for expressway and rapid transit improvements in the Northeast Corridor from the Eastern Massachusetts Regional Planning Project follows. They have been divided into near (to 1975) and far (1975-1990) term programs.

Highway-Committed Projects

- construction of I-95 from Danvers to Revere
- reconstruction of I-95 from Salisbury to Danvers

Highway-Near and Far Term

- up-grading of I-95 from Cutler Circle in Revere up to the Tobin Memorial Bridge in Chelsea
- construction of the Beverly-Salem Connector
- construction of the Revere Beach Connector
- construction of a Third Harbor Crossing

- construction of a Shore Expressway from the Third Harbor Crossing to I-95 in Saugus

Transit-Committed Projects

- none

Transit-Near and Far Term

- extension of Blue Line rapid transit to Pines River from Wonderland Station
- extension of Blue Line rapid transit to Salem from Pines River.

It was the conclusion of the Eastern Massachusetts Regional Planning Project report that neither Plan A or C proved to be completely adequate, because the projected 1990 traffic loads are greater than the capacity of certain proposed highways. However, the analysis of the alternatives resulted in the above recommended plan that combined the tested and proven facilities of both. As a consequence, the above recommended plan was more extensive than either alternative, recognizing, further, that it must be continually tested, adjusted, refined, and updated as necessary.

C. GROUND ACCESS TO BOSTON-LOGAN INTERNATIONAL AIRPORT

Ground access for person travel to Logan Airport at the present time is primarily by private auto with little use being made of mass transit. Approximately 4% of all person trips to the airport are made by mass transit, while 84% are made by private auto and the remaining 12% by limousine and taxi. 2/

Ground access for freight is all by truck. The air freight same-plane service to more than 100 North American cities and elsewhere throughout the world serves over 4000 New England businesses.

2/ Preliminary results from the Logan Airport Travel Survey being carried out by the Massachusetts Port Authority, the Massachusetts Bay Transporta-Authority and the Massachusetts Department of Public Works

Airport Population as Related to Ground Access: Although air passengers represent the greatest numbers at Boston-Logan International Airport, two other categories make up the airport's total population. Past surveys by Wilbur Smith and Associates showed that each passenger generates 0.8 visitors. The third significant group are the airport employees. Using 1967 passenger figures, the following percentages were developed:

Population Composition at Logan	
Air passengers	48%
Visitors, sightseers	38%
Employees	14%

These percentages were based on 7.7 million annual total passengers and daily figures of 30,000 passengers, 24,000 visitors, and 8,000 employees. These were used to project the future population for the total airport. Roadway and parking requirements are related to these population figures using the measurement equations shown below.

Measurements from Logan historical data.

1. Annual enplaned passengers/250 = Daily enplaned passengers
2. Daily enplaned passengers x 0.12 = Peak Hour enplaned passengers
3. Daily vehicles one-way = Daily enplaned passengers x 1.4
4. Peak hour vehicles one-way = Daily Vehicles one-way x 0.10.

From these historical ratios and air passenger traffic projections, airport generated daily and peak hour traffic were obtained.

A summary of past, present, and future airport passenger, vehicle, and parking figures shows the following:

Year	Annual Enplaned Passengers	Daily Enplaned Passengers	Daily Population	Peak Hour Pass.	Peak Hour Daily Vehicles	Required Public Parking
1968	4,425,000 (A)	17,700	73,900	2125	2475	6,325
1970	4,678,800 (A)	18,785	78,925	2255	2515	6,715
1975	6,335,200	25,340	105,800	3040	3550	9,050
1980	8,256,100	33,025	137,876	3965	4625	11,800

Now with these measures and the following highlights, the impact from a traffic standpoint of Logan Airport on the Northeast Corridor can be better appreciated.

Of the total of about 6,700,000 vehicle trips each day in the region, about .75% or 50,000 are to or from Logan Airport. Logan Airport's 50,000 trips are about 6% of all vehicle trips in the Northeast Corridor. An examination of Logan's impact on nearby facilities follows in the next section. First a review of highway facilities and then transit.

HIGHWAY

State Highway C-1 (McClellan Highway)

This highway lies immediately west of the airport and runs in a north-south configuration connecting the Callahan and Sumner tunnels with North Shore communities. There are three lanes in each direction with a design capacity of 1,200 vehicles per hour per lane or a total capacity of 3,600 vehicles per hour per direction. Immediately to the north and south of the airport the roadway narrows to two lanes in each direction and a resulting design capacity around 2400 to the north and 1312 in the tunnel to the south.

At present this road does not operate at its designed peak hour capacity, because of these constrictions.

Preliminary results from the Logan Airport Travel Study indicate that of the total airport daily generated vehicles approximately 80% enters or

leaves the airport via its main inbound or outbound roadway. The airport outbound roadway, for example, splits into three directions in the following manner:

Ramp A to the MBTA Blue Line Station (and airport recirculation)

Ramp B to Highway C-1, Southbound (Boston)

Ramp C to Highway C-1, Northbound

In August of 1969, a vehicle road survey indicated that of the total traffic exiting the airport (on the outbound roadway) the average percentage breakdown by ramp was the following:

Ramp A	7.7% 1/
Ramp B	62.9%
Ramp C	29.4%
	100.0%

A more recent survey conducted in June, 1970, for the same conditions as above provided the following average percentage breakdowns:

Ramp A	8.2%
Ramp B	57.5%
Ramp C	33.2%
	100.0%

Allowing for seasonable changes in traffic characteristics, airport employees, etc., these two surveys are quite similar, enough so that their average can be considered as an adequate measuring device for purposes of this analysis. Thus, we have the following relationship:

Ramp A	8.0%
Ramp B	60.5%
Ramp C	31.5%
	100.0%

1/ This ramp provides a means for vehicles to recirculate the airport.

Based on traffic counts and ramp % as shown, the following table displays the Airport Roadway's impact on Route C-1 during the Peak Hour.

	Route C-1 Average Daily Traffic		Route C-1 Peak Hour Vehicles 1/		Airport Roadway Peak Hour Vehicles	
	SB	NB	SB	NB	IB	OB
1970	22,600	23,860	1,980	2,270	812	771
1975	27,226	28,749	2,385	2,734	1,339	1,230
1980	32,700	34,579	2,865	3,289	1,745	1,603

SB - Southbound; NB - Northbound

IB - Inbound; OB - Outbound

The above analysis illustrates that Highway C-1 north of the airport interchange (where it constricts to two lanes) was still just below its rated design peak-hour capacity in 1970. (2270 vs 2400) The problem area, however, is on C-1 between the airport interchange and the Sumner-Callahan Tunnels' restricted capacity, which contribute to the traffic congestion today.

<u>Sumner-Callahan Tunnels</u>

These tunnels are already operating above capacity at peak hours. The limiting factor here is not necessarily the tunnels themselves, but their access roads at both the Downtown Boston and the East Boston portals and the toll booths. Many engineers believe that the design capacity could be increased significantly if the Downtown access point could be improved. However, even with such an improvement, the tunnels would still be operating above peak hour capacity. The airport presently contributes approximately 57.1% 2/ of the peak hour volume; however, if a Third Harbor Crossing is

1/ Includes Logan traffic. For example, in 1970, of the 1,980 vehicles southbound on Highway C-1, 812 branched off to Logan.

2/ From an average of 59.4% and 54.8%

not realized, Logan's share of tunnel traffic will undoubtedly increase since its annual growth rate is higher than the tunnels.

Tobin Memorial Bridge

At present, this facility is operating near capacity during some péak hours, but has considerable capacity in off-peak periods. Its traffic growth has been approximately 4.2% per annum, but this figure has been slowly increasing. This trend will probably continue as the existing tunnels become more congested with some traffic diverting to the bridge. To determine a direct impact from Logan at this time is difficult inasmuch as the bridge does not serve Logan directly, but is is an alternative for those traveling in the Northeast Corridor normally using C-1. However, it is beyond the scope of this analysis to ascertain how much of a diversion there would be.

Southeast Expressway and Central Artery

The Southeast Expressway and Central Artery is one of the most congested main arteries in the Metropolitan Boston roadway network during peak hours. Traffic on this road will continue to grow as it is the only current means of transversing the City of Boston from north to south. However, construction of the Southwest Expressway, I-95, would alleviate the Southeast's overload, while a Third Harbor Crossing would help the Central Artery. Logan bound traffic is definitely affected by this road since approximately 50% of tunnel traffic is directly related to the Central Artery.

Third Harbor Crossing

The Massachusetts Turnpike Authority in 1968 recommended an immediate go-ahead on a Third Harbor Tunnel. It is even more apparent at this time that this tunnel is required. The proposed tunnel, which would run from the Massachusetts Turnpike Extension to the C-1 airport interchange, would

provide the cross-Harbor capacity needed until 1990, in conjunction with the present tunnels and the Tobin Memorial Bridge. This tunnel would provide much better service to the airport for all travelers from the south and west, for it would eliminate the need to travel on the Central Artery and the present tunnels. Even if the airport projected air traffic increases were not realized, this tunnel is already required and will become more necessary as time goes on. The new Harbor Crossing will, of course, be a trip generator, but even with the new trips generated, all traffic will be easily handled until the 1990 period.

<u>Leverett Circle Bridge</u>

Although the Leverett Circle Bridge would not carry any Logan-generated traffic, it would play a major role in the reduction of congestion on the Central Artery and consequently improve the overall traffic situation. By diverting traffic, a substantial reduction in volume on the Central Artery could be affected, which would, of course, have the secondary effect of lessening the impacts of Logan-generated traffic on the Boston Roadway network.

Furthermore, traffic on Storrow Drive that is destined for I-695 and the Tobin Bridge would be removed from the Central Artery, which in turn would lessen congestion on this vital traffic link.

<u>Massachusetts Turnpike Extension</u>

This portion of the Massachusetts Turnpike begins at the Turnpike's Route 128 interchange and terminates with the Southeast Expressway just south of South Station.

This road will become more extensively used by Logan-bound traffic inasmuch as a major share of Logan's air travel market lies to the west and southwest of Boston and is well served by this road. The extension is presently operating below capacity during peak hours and will probably not reach peak

hour capacity until the latter part of this decade.

It is important to note that the airport-bound vehicles using the Turnpike Extension must now traverse two of the most congested elements at peak hour in the Metropolitan Boston Roadway network - the Central Artery and the Tunnels. Thus, the need becomes quite apparent, once again, for a Third Harbor Crossing.

Secondary Airport Access Roads

Preliminary results from the Cordon traffic count of the Logan Airport Traffic Study indicate that on an average weekday for a 24-hour period approximately 81% of the traffic counted, involving Logan access roads, occurred by the Route C-1 connecting ramps. Secondary access route (Porter and Frankfort Streets) accounted for 10% and 9% of the traffic counted, respectively. However, it is important to note that not all of the recorded traffic is related to the airport. For example, it is known that local traffic traveling from the community on the south side of the airport to north bound on Highway C-1 will use airport roads to traverse this route, although it is quite difficult, if not impossible, to determine this exact percentage.

These secondary access routes, when used for airport related business, serve Logan's ancilliary facilities including air cargo terminals, general aviation, etc.

Porter Street lies in an east-west direction on the south side of the airport, between the Callahan Tunnel Toll-Plaza and the airport boundary where it terminates. The airport road that intersects with Porter Street serves the rent-a-car, air cargo and aircraft maintenance facilities, general aviation area, U. S. Post Office and the Bird Island Flats area. All airport oriented traffic to these facilities use roads on airport property.

Frankfort Street connects the Logan community and facilities on the north side of the airport with ramps to and from Highway C-1. These facilities are predominately air cargo, maintenance and offices.

Preliminary results from the Logan Airport Traffic Study shows that the volume on an average weekday for a 24-hour period (inbound on Frankfort Street) is as follows:

TABLE

	Percent
Private automobiles	79
Taxis	2
2-axle trucks	14
Multi-axle trucks	5

As movements to and from the ancilliary airport facilities increase in the future, internal airport roadways will have to be improved to accommodate the anticipated demand.

Transit Service

Most passengers and employees arriving (or departing) at the airport by bus use the MBTA's Blue Line rapid transit. The airport's station on this line lies slightly more than a mile from Logan's terminal buildings, making it necessary for the users to transfer to a bus which shuttles between these two points. In 1970, a 2-month survey revealed an average of 2,942 persons (one-way) used this system daily. Using the following 1970 percentage breakdown by user types, this means that about 1560 were enplaned passengers.

Airline Passengers	53%
Airport Employees	24%
Visitors (Including sightseers)	14%
Other	9%

Preliminary analysis by the MBTA of one segment of the 1970 Logan Airport Travel Study has revealed certain information pertinent to this analysis.

Approximately 50,000 person trips were made from Boston-Logan International Airport during the average weekday in June, 1970. It is estimated that in excess of 20,000 deplaning air passenger trips were included in the 50,000 person trips. Previous surveys at Logan have shown that air travelers make up the largest single market for transit trips to and from the airport. Air travelers also comprise the largest segment of the total ground trip market to and from Logan (55% - 65% of ground trips are made by air travelers). Thus, an analysis of the deplaning air travelers accounts for approximately 50% of the potential transit market.

Blue Line

Analysis of the deplaning air passenger trips destined for the Blue Line market area does not indicate encouraging results. Improvements to the Blue Line in the Northeast Corridor would benefit a relatively small number of one-way air passengers. There are approximately 1480 deplaning air passenger trips from Logan to the North Shore market area towns during a weekday. Only 40 of these trips are made by transit which indicates a very poor modal split (2.7%). The towns which generate the largest number of deplaning air traveler trips (50 or more trips per town) in decending order of importance are: Lynn, Peabody, Marblehead, Gloucester, Beverly, Salem, Swampscott, Lynnfield, Danvers, Manchester, Revere, Saugus, and Ipswich. Chelsea, Winthrop, and East Boston are not included in the above, since these areas would not be affected by Blue Line improvements at the Corridor level e.g., extension beyond Wonderland to Pines River and the additional parking. East Boston, Winthrop, and Chelsea generate approximately 360 deplaning air passenger trips of which approximately 25 are made via transit (7% modal split). Transit

access improvements to Logan which would affect East Boston, Winthrop, and Chelsea (e.g., rail spur into Logan or direct bus service) might be expected to attract up to 110 transit trips to these areas by deplaning air passengers, assuming an optimistic modal split of 30%. This traffic potential does not include Airport employees, who are probably concentrated in the Blue Line market area and would account for a substantial transit market. Travel data for the 10,000 Airport employees is not yet available and can only be speculated upon at this time.

Assuming that Blue Line improvements could generate a 30% modal split for the North Shore deplaning air passenger market (this is an optimistic assumption based on Cleveland-Hopkins survey results) then only approximately 445 transit trips (i.e., 400 new transit trips) could be expected from the deplaning air passenger market to the North Shore. The existing low modal splits to the North Shore indicate difficulties in competing with the auto access mode.

Green Line

The Western Corridor generates nearly twice as large a market for deplaning air passenger trips than the Northeast Corridor. The Riverside Line market area, which can be considered a subdivision of the Western Corridor being mainly composed of Newton, Brookline, Framingham, Wellesley, Needham, and Natick, generates approximately 2,160 deplaning air passenger trips, which include approximately 150 transit trips (7% modal split). Based on the assumption that transit access improvements between Logan and this market area (e.g., extension for Framingham, upgrading and through routing Riverside Line) could produce a 30% transit ridership, then approximately 650 of the deplaning air passenger trips would be attracted. Considering the total Western Corridor market which extends out beyond Route 495, the total number of deplaning passenger trips is approximately 3,160 of

which 190 are transit (6% modal split). A 30% modal split for this expanded market area would generate approximately 950 transit trips (i.e., 760 new transit trips).

Comparison of the Western and Northeast Corridors shows both larger volumes (3,160 vs. 1,480) and higher modal splits (6% vs. 2.7%) for the Western Corridor which attracts nearly five times as many transit trips (190 vs. 40) as the Northeast Corridor.

The reason that a greater percentage of the deplaning air passenger trips are made via transit to Western Corridor destinations than to the North Shore corridor destinations might be explained by the large number of transit trips to Newton. Newton generates approximately 27% of the total trips to the Western Corridor and 8% of these trips use transit. Newton enjoys convenient access to the Riverside Line which passes through the center of town with seven transit stops in Newton. Conversely, the largest generators in the Northeast Corridor are Lynn, Marblehead, Beverly, and Gloucester, which account for 35% of the trips to this corridor. These towns are located well beyond the Blue Line terminal and generate a low 2% modal split. Revere, which has three Blue Line stations within its boundaries, produces less than a 2% modal split for deplaning air passenger trips. The differences in Western and North Shore Corridor modal splits are thus believed to result from travel time factors. Travel time ratios (transit plus auto door-to-door travel time) and time differences (transit minus auto) for the Northeast Corridor are generally higher than for the Western Corridor. Out-of-pocket travel costs are not considered to be a major factor in transit use for air travelers; however, the transit travel costs to the Western Corridor are more competitive with out-of-pocket auto costs than for the Northeast Corridor (e.g., Tunnel and Turnpike tolls are high for Western Corridor auto trips which tends to make transit more attractive).

Analysis of the residence (Massachusetts resident or non-resident) of deplaning air travelers with destinations in the North Shore and Western Corridors indicates that approximately 50% of the trips to each corridor are made by non-residents of Massachusetts. The high percentage of non-residents can help explain the low modal splits, but does not explain the differences in modal split between the Northeast and Western Corridors.

Boston accounts for 25% of the total deplaning air passenger ground trip destinations and represents the largest market concentration. Downtown Boston accounts for more than 60% of the deplaning trips to Boston (approximately 3,600 trips to Downtown). Only 7% of these trips use transit (255 transit trips). The non-transit trips to Downtown Boston are primarily taxi trips which account for over 50%; most of the remaining trips are equally split between the private car and limousine (17% each); rental car trips account for only 5%.

The low modal split to Downtown Boston can be explained by examining trip purposes. More than 60% of the trips to Downtown are for company business which produces less than 4% modal split. This is probably due to the availability of expense accounts associated with company business trips.

Approximately 30% of the trips to Downtown are made for pleasure and personal business purposes; these trips exhibit relatively high modal splits of 12% - 15%. Further examination indicates that over 80% of the deplaning passenger trips to Downtown Boston are made by out-of-state residents which would account for the low transit and high taxi use.

The largest number of trips to Downtown are concentrated in Zone 34 which encompasses Prudential Center (and Prudential Station). Approximately 20% of the trips to Downtown are concentrated in this zone which produces a 2.8% modal split. Most of the trips to this zone use taxi.

The next largest concentration of trips are in Zone 30 which encompasses Park Square. Zone 30 accounts for 18% of the trips to Downtown and produces a modal split of 4.6%. Most of the trips to this zone use taxi and limousine service.

The remaining trips to Downtown Boston are distributed rather sparsely throughout the Downtown area, but are generally located along the Green Line service area. It appears unlikely that an appreciable number of the Downtown trips could be attracted to use the existing transit lines unless a major effort is devoted to advertising the transit service and actual use of the service is made considerably easier. Cleveland, for example, provides door-to-door service from the CBD while the Boston system requires two transfers from the Green Line area, which naturally inhibits use by the air passengers unfamiliar with the system. Essentially door-to-door service will have to be provided to achieve high levels of transit use. The high concentration cf trips at Park Square and Prudential Center indicates promising possibilities for a reliable door-to-door bus service between these areas and Logan.

<u>Other Lines</u>

The non-Downtown Boston areas (e.g., Brighton, East Boston, Mattapan, etc.) were examined to determine market potentials. The non-Downtown Boston areas account for 38% of the deplaning air passenger trips to Boston or approximately 2,200 trips. The non-Downtown Boston destinations, unlike Downtown Boston, generate a 16% modal split. This higher modal split is explained by differences in the trip purposes for these two areas. Sixty-four percent (64%) of the trips to Downtown Boston are for company business (which exhibits very low modal splits), whereas non-Downtown Boston destinations attract only 39% company business trips. Fifty-two percent (52%)

of the trips to non-Downtown Boston are for pleasure and personal business, which trip purposes show consistently higher modal splits than company business trips. Jamaica Plain and Brighton attract the largest number of non-Downtown trips (over 50% of the non-Downtown trips) and produce 18% and 24% modal splits, respectively. The reason for these relatively high modal splits is that large numbers of the trips to these destinations are pleasure trips which produce 27% modal splits and school trips to Jamaica Plain which produce a 35% modal split.

Cambridge is the largest attractor of deplaning air passenger trips next to Downtown Boston. Cambridge generates a 16% modal split similar to non-Downtown Boston destinations. This relatively high modal split results from a large percentage of pleasure, school and personal business trips which exhibit 20% - 22% modal splits. Over 40% of trips to Cambridge use taxi service followed by over 30% who use private car.

Brookline attracts approximately one-tenth the number of trips attracted to Boston. Brookline generates a 13% modal split due to a high percentage of pleasure trips which generate a 16% modal split. The inner zones of Brookline which have convenient access to the Green Line produce a 14.6% modal split while the outer zones do not produce any transit riding. Over 50% of the trips to Brookline were made using private auto while 30% used the taxi service.

Bus/Limousine Service

At the present time 5 bus or limousine companies (exclusive of MBTA) provide services between Logan and several communities. These include:

Company	Service To:
Airport Limousine Service	Boston hotels (Downtown)
Hudson Bus Company	Saugus, Revere, Chelmsford, Lowell,

	Bedford, Burlington, Wakefield and Peabody, Massachusetts, Nashua and Manchester, N. H.
C & J Transportation	Dover, Durham, Portsmouth and Hampden, N. H.
Short Line	Providence, Rhode Island

These services average approximately 10,000 passengers per month or about 1.25% of Logan's total passengers. Discussions are currently underway, with several transportation companies, to provide improved and new services between Logan and Boston area communities; Hartford, Connecticut; and selective Maine communities. As well as improving and expanding these services, the Authority is developing a promotional campaign to make air passengers aware of them.

Helicopter Service

Scheduled helicopter service, based at Boston-Logan International Airport began about a decade ago providing service between Logan and numerous locations largely along Route 128. During 1967, for example, Air General, Inc. conveyed 23,452 passengers which accounted for .32% of Logan's total passengers, but due to a subsequent lack of patronage and high costs, this company was forced to cease its operations. At this time, there are no known plans to revitalize this service. However, if congestion on the metropolitan Boston roadway system becomes unacceptable, a renewed demand for a helicopter service may be realized, thereby providing a possible viable alternative means of access to Boston-Logan International Airport.

Taxis

As was demonstrated, taxis represent the second largest mode of ground transportation at Logan International Airport. A recent review of taxi ticket stubs purchased by the cab operators (outbound from Logan) revealed that over a 36 day period in 1971, there was a daily average of 1958 cabs with a peak day of 2700 and a low day of 1100. As was indicated in the MBTA's pre-

liminary review, by far the majority of taxi trips to and from Logan operate to the downtown Boston area.

High-Speed Overwater Access

Presently there are not any overwater commuter services provided to the public in the Metropolitan Boston area. However, the possibility exists that high-speed air-cushion waterborne vehicles (ACV) may, in the near future, be capable of providing fast and convenient service between Boston and the many communities bordering navigable waters, if the need for such a service can be demonstrated.

In this regard, preliminary studies are underway by the Authority concerning the need for and feasibility of such a system that if realized would not only serve the commuter, but might also provide access to the Harbor Islands during off-peak commuter hours and weekends for recreational purposes. As an initial step, the Authority has signed a contract with a company that will provide service from various South Shore communities to Boston-Logan International Airport, as well as from a point along the Boston waterfront to the airport.

Other Approaches

Decentralization of Cargo and Passenger Collection

As an alternative to the continued utilization of low capacity private autos, should access become even further congested, consideration will be given to remote terminals and/or passenger collection points. The Port Authority, as part of the planned, but recently deferred South Station project, had comtemplated a downtown terminal but received little support from the airlines due to the proximity of the airport proper to downtown Boston. These remote terminals could consolidate passengers into bus loads and offer savings in fares compared to taxis and help reduce travel congestion as well.

Terminals or collection points migh be located at I-95 and Route 128 in the south, at the Turnpike and Route 128 in the west, and at I-93 and Route 128 in the north. Since 50% of the air passengers originate in other than Massachusetts, these terminal or collection points could intercept both auto and bus passengers from the other States.

With regard to air cargo, the Authority, recognizing the limit of airport property, has acquired a building off the airport for use as a remote air cargo terminal containerization facility. These containers will be trucked directly from these facilities to aircraft at the airport via Highway C-1. Thus, this facility will reduce the number of vehicles entering the airport. Further consolidation points can be developed as needs demand.

Advanced Transport Systems

Presently there are many advanced schemes to handle both urban circulation and distribution problems as well as point to point transit needs. The Tracked Air Cushion Vehicle slated for demonstration at Dulles International Airport in Metropolitan Washington is an example of one of these systems. Others such as the Scherer Monobeam, the Aerial Transit System, and General Electric's large rubber-tired aerial transport system are indicative of the range of possibilities in the fast transit link system area which might have future application at Logan. The Port Authority considers these as potential solutions which will be studied when the more prosaic systems can no longer handle the airport access job.

D. LOGAN AIRPORT ROADWAY AND TERMINAL IMPROVEMENT PROGRAM

Airport Roadway System

The existing main access roadway is presently three lanes wide in each direction with a rated hourly capacity of 3600 vehicles per direction. This roadway is essentially a loop that connects directly to Highway C-1 and

serves as the primary feeder for not only the terminal area, but also various ancillary facilities. This roadway will be operating at its maximum peak hour capacity sometime in the 1976 period. There is one signal on the roadway which presently causes some delays. This arrangement will be reviewed to see what traffic engineering solutions appear most feasible. Capacity increases in the airport roadway system can be developed without great difficulty. This does not appear to be a present or future constraint on access.

Public Parking

At present there are approximately 6000 available public parking spaces in the terminal area (not including 175 metered spaces). Included in this are 3300 spaces in the three-level Central Garage to which two more levels are currently being added. With this addition, 2200 parking spaces, there will be a total of approximately 8000 public parking spaces available for Logan patrons in the Summer of 1971. This will be quite sufficient to handle the forecasted parking requirements until 1974-1975.

With the completion of the New South Terminal and International Terminal buildings in 1974, there will be an addition of approximately 3600 public parking spaces. There will then be a grand total of some 11,600 spaces available in 1975, which will be sufficient to satisfy the 1980 requirements.

A more distant improvement capability is the expansion of the central garage to the west by five levels, which would provide additional parking capacity. Exact numbers are not possible at this time because this particular program is only at the conceptual stage. The ultimate master plan for public parking facilities at the terminal area will accommodate about 15,000 spaces, if this is feasible in keeping with access needs and policies.

Sub-Terminal Complex and Intra-Airport Transit System

This conceptual plan includes a Sub-Terminal facility that would be

located in an area west of the central garage between the inbound and outbound roadways. As it is now envisioned, this facility will house rent-a-car operations including auto storage spaces, gassing, washing, and a sub-terminal, which would provide a drop-off and pick-up (both for passengers and baggage) capability. This would, among other things, relieve curb-side congestion during peak hours at the four unit-terminal buildings.

An integral element of this entire plan is an intra-airport transit system, which would be a fully automatic and computerized system utilizing small vehicles either suspended from, or supported by, an elevated guideway. As envisioned, this system would - as a first phase - connect the Sub-Terminal and Central Garage facilities with the four unit-terminals. It's second phase would extend out from the sub-terminal to the existing MBTA Blue Line rapid transit airport station. This would not only eliminate the need for the present shuttle bus operation, but more importantly provide a clean, comfortable and convenient conveyance that would strengthen the link between this transit line and the airport. This system, then, together with possible improvement of the MBTA's systems could effectively offer an attractive alternative to the automobile in terms of convenience, cost, and travel time.

E. CONCLUSION

From the previous analysis certain alternative solutions towards improving Boston-Logan International Airport's ground access problems become apparent.

In order of impact and priority:

1. Improved Regional Highway System

Since most of today's travel to and from the airport is by private auto, trucks, taxis and buses, the greatest impact on the solution to this problem can be made for today's traffic and for that of the near term future, by improving key elements in the regional highway system. These improvements will relieve peak hour congestion at strategic points in the ground access system serving Logan International Airport. The key elements needed are improvements in the entrance and exit to the Sumner-Callahan Tunnel and construction of both a third Harbor Crossing and the Leverett Circle Bridge. By implementing these planned links in the region's highway network much of the highway access problem for Logan would be resolved.

2. Improved Public Transit

In order to accomodate future travel to the airport, dependence on the highway links alone will not be satisfactory. Although present transit usage is minor (4%), there exists the capability for significantly improving access by transit.

Express buses from strategic points in the region as well as a fast and efficient intra-airport transit link from the airport station to the

terminals would be meaningful steps in implementing improved public transit.

3. Decentralization of Cargo and Passenger Collection

The Authority has already moved on cargo decentralization and will be reviewing the needs for passenger decentralization through remote terminals or collection stations, where passengers can be brought together and conveyed to Logan by means of buses.

4. Development of Water Access

The Authority has recently contracted for a company to run high speed air cushion vehicles to connect the airport to various shore points including a location on downtown Boston's waterfront.

5. Improved Airport Roadway System

The Authority has already separated vertically certain terminal approaches in a successful effort to minimize roadway problems at the terminals. Consideration of other roadway improvements will go hand-in-hand with terminal modernization.

6. Cooperative Regional Planning

The Massachusetts Port Authority is working with the various regional, state and federal agencies to develop plans for the future of the regional transportation system.

As a member of the Governor's Advisory Council on Transportation, the Executive Director is contributing to regional and state transportation plans.

Under the leadership of the Metropolitan Area Planning Council the Massachusetts Port Authority has worked with the Massachusetts Department of Commerce and Development, the Massachusetts Department of Public Works, the Massachusetts Aeronautics Commission and the Massachusetts Bay Transportation Authority on the Boston Metropolitan Airport System Study, aimed at determining the need for a second airport.

Presently the Authority is represented on the Governor's Transportation Planning Review Study which is involved in a comprehensive re-study of transportation planning within Route 128.

These kinds of established interagency efforts are the chief means for the Massachusetts Port Authority to help develop the ground access it needs at Logan Airport.

SECTION IV

ENVIRONMENTAL IMPACT OF DIKES, LAND FILLS AND DREDGING

SECTION IV

ENVIRONMENTAL IMPACT OF DIKES, LAND FILLS AND DREDGING

INTRODUCTION

This section of the Study details the controls which will be provided by Contract Specifications and Engineering Supervision to insure that the quality of land fill and dike materials, the construction methods employed in their use and the disposal of dredged material will not affect short or long term water quality in Boston Harbor. Esthetics of the construction project and impact on rodent habitats are also discussed. A report of the environmental investigations conducted by the engineering firm of Fay, Spofford and Thorndike, Inc. is included in the Supporting Documents section of this Study.

SUMMARY OF FINDINGS

In the considered judgement of the Massachusetts Port Authority, the dikes, land fills and dredging proposed at Boston-Logan International Airport will not contribute to harbor pollution but will, in fact, improve the natural esthetics of the area and discourage rodent habitats.

A. DIKES AND LAND FILLS

Dikes will be constructed of stone in deep water and gravel protected by stone in shallow water. Land fills within the dikes will be composed entirely of gravel.

1. Water Quality Controls

Control of material quality and construction methods will be provided by rigid contract specifications, enforced by the Project Engineer.

a. Stone

- Stone is as inert as any natural substance which is available on earth.
- Before a quarry will be approved as a source, the stone will be sampled to insure that it meets specifications and will be chemically tested for soundness and hardness to insure that it will not disintegrate in the salt water environment or under the action of alternate freezing and thawing.
- Quarries will be inspected periodically to insure that organic material existing on the surface has been properly stripped and is not contaminating dike material.

b. Gravel

- The composition of gravel material found in this region is relatively uniform and consists of approximately 60% quartz, 35% feldspar and 5% ferro magnesium, that latter being insoluble in water for up to 10,000 years.
- Contract Specifications require that the gravel used for dikes and land fills be a clean granular material, free of organic matter and further, they strictly limit the amount of fine material permitted.

This limit is such that any fines released into the harbor waters during construction will be minimal. Tests conducted by Fay, Spofford and Thorndike have also indicated that the composition of fines which may escape is such that they will settle out rapidly and will not remain in suspension long enough to have a detrimental affect on shellfish or other marine organisms beyond the immediate dike area.

- Gravel will be tested for compliance with Contract Specifications at the pits prior to their approval as sources and periodically thereafter, both at the pits and upon delivery to the construction site.
- Gravel pits will be inspected periodically to insure that organic material on the surface has been properly stripped and is not contaminating dike or fill material.

2. Impact on Inland Areas

a. Sources of Material

- There is no way in which the Massachusetts Port Authority can determine the specific sources of dike and fill material prior to the letting of a Contract under the competitive bidding process. It is unable, therefore, to evaluate the exact impact which removal of material would have on any specific area.
- Present experience indicates that inland material would come from areas no closer than 30 miles from Boston and no further than 100 miles.

- Because of the quantity of materials required and the logistics involved, it can be assumed that there will be a number of different material sources, thus limiting the impact on any one area.
- There are in existance a number of commercial sources of stone and gravel which are licensed and regulated by local authorities.
- The Contractor will be responsible for locating and obtaining all necessary approvals for his material sources.

b. Routes and Methods of Transportation

- As in the case of material sources, the Massachusetts Port Authority has no way to determine the specific routes or methods of transportation which the Contractor will use, prior to contract award under the competitive bidding process.
- Experience does indicate that trucking is generally economically feasible only for haul times of one hour or less. It can be assumed, therefore, that materials within one hour's travel time of the construction site will come by truck over existing interstate highways and that materials beyond that limit would be transported by rail. Rail deliveries would be made at a local off-loading point from which delivery to the site would be accomplished by truck, hydraulic pipeline or conveyor.
- A possibility also exists that a suitable and approved source of fill material can be located in the ocean. In this instance, the material would be delivered to the site by barge or similar waterborne conveyance.

3. Impact of Rock Dikes on Asthetics

Aesthetics is one of many things that is normally considered in the design of any structure exposed to public view. There must be a balance between aesthetics, economy of construction, economy of maintenance, and the ability of the structure to perform its functions with efficiency and with the least adverse effect on its surroundings.

a. The possible structures that could be used to retain the fill material are as follows:

- A timber bulkhead
- A steel sheet pile bulkhead
- A structural concrete retaining wall
- A stone riprap face on an earth or stone fill

b. For a waterfront structure which does not require a vertical face for the docking of vessels and where space permits, a sloping surface is considered most desirable. A sloping face permits waves and the wash from boats and ships to dissipate without causing a counter wave. Vertical surfaces reflect waves and the wash from boats operating in the area which can be dangerous to the operation of small boats. It also provides an access to land for swimmers who might capsize in small boats in the area.

c. Timber bulkheads have a limited life, require constant maintenance and ultimate replacement. Timber bulkheads originally constructed at the

airport had to be protected with stone riprap to prevent their total collapse.

d. Steel sheet pile bulkheads require maintenance, often including electronic protection, are not inexpensive and present an asthetically displeasing appearance.

e. Concrete retaining walls are expensive and the life of concrete exposed to tidal action is limited. In addition, a review of concrete structures in the area indicates staining from contaminated water which detracts from their appearance.

f. The New England area is no stranger to rock outcrops facing the ocean. A rock dike or a rock protected earth fill is no more expensive to construct than any of the other types; maintenance is nominal, and there are instances of such installations in the area which are older than living memory. Dikes of this type present an asthetically pleasing appearance which blends well with the New England scene. Because they appear to satisfy all criteria, they were chosen for this project.

4. Dikes as a Rodent Habitat

It has been suggested that stone riprap protected slopes are an invitation to infestation by rats. Experience with rat control indicates that where there is no food supply there are no rats. If there are rats currently living in the area in which the stone structures will be constructed, they may make use of the interstices in the stone. Since the stone offers no food supply, the rat population should not increase. Adequate rat control programs are available and, if they should become a problem, they can be controlled.

B. DREDGING

1. Permit Requirements

a. In order that dredged material may be disposed of at sea, a permit must be obtained from the U.S. Army Corps of Engineers. In support of the permit application, a chemical analysis of the dredge material is required; the results of which must meet certain criteria established by the Environmental Protection Agency. These tests have been made and the results are summarized in Exhibit 10.

b. A comparison of the test summary against the percentage of elements for which Federal limits have been set, indicates that the material is relatively clean and may qualify for disposal at sea, even though it slightly exceeds the permissible nitrogen level and does not fully meet the formula prescribed for the relationship between volitile solids and chemical oxygen demand.

2. Disposal Alternatives

a. Disposal at Sea

. If a permit for disposal at sea is obtained and an approved disposal site is designated by appropriate federal authorities, this disposal method will be employed.

SUMMARY OF CHEMICAL TESTS ON MUD TO BE DREDGED

ITEM	LIMIT % DRY WEIGHT	% SAMPLES LOGAN MUD
Volatile Solids	6	2.93
Chemical Oxygen Demand (C. O. D.)	5	4.42
Total Kjeldahl Nitrogen	0.10	0.12
Oil-Grease	0.15	0.016
Mercury	0.0001	0.000077
Lead	0.005	0.000053
Zinc	0.005	0.000085

- Dredging will be accomplished by bucket type dredges, the material loaded onto bottom dump barges and transported to the disposal site.
- Laboratory tests for settleability indicate that the dredge material does not remain in suspension for a long period of time and will not be carried far from the area of dredging or disposal.

b. <u>Disposal on the Airport</u>

- If disposal at sea is not allowed, the dredge material will be disposed of in the large lagoon on the airport, which is enclosed by the parallel 4-22 Runways, Runway 15R-33L and the North Taxiway.
- Suitable control structures will be constructed to assure that the amount of solids in the effluent from the area meet Federal standards. This can be accomplished by retention in settling ponds and the construction of weirs and baffles.
- Treatment of the effluent water to reduce solids to an acceptable minimum level is feasible and will be required.

SECTION V

SAFETY CONSIDERATIONS

SECTION V

SAFETY CONSIDERATIONS

INTRODUCTION

This section of the Study reviews safety considerations with respect to harbor shipping and the effects of the project improvements on safety in general.

SUMMARY OF FINDINGS

Detailed study of all safety aspects related to the airfield improvements proposed by the Massachusetts Port Authority reveal no adverse impacts upon maritime interests and, in fact, indicate that the margin of safety for airfield operations in general will be improved.

A. MARITIME INTERESTS

1. Background

In response to receiving notice that the Massachusetts Port Authority had applied for a permit to fill a portion of the Boston Harbor for improvements to the Logan International Airport, the American Institute of Merchant Shipping, which represents oceangoing vessels of all types, examined the proposed improvements to determine their affects on the separation between aircraft and vessels in the Boston Harbor Main Ship Channel, the Bird Island Flats Anchorage and the President Roads Anchorage. On March 8, 1971, the American Institute of Merchant Shipping requested that the U.S. Army Corps of Engineers withhold issuance of

the permit pending resolution of any problems with the safe operation of ships and aircraft in those areas. (Exhibit 11)

2. Aeronautical Analysis

a. The Massachusetts Port Authority undertook an analysis of all possible aeronautical conflicts which the proposed airfield improvements could create with respect to shipping and maritime interests. Results of that analysis are summarized below:

- The proposed improvements can have no affect whatever on the main ship channel or the Bird Island Flats Anchorage, since landing thresholds on the Runway 4L and 9 extensions will be displaced and will remain precisely at their present locations.
- The 50:1 approach slope and 3 degree glide slope to proposed Runway 33R will be only 4 feet lower over the President Roads Anchorage than these same slopes to existing Runway 33L. (See Exhibits 12 and 13)

b. An analysis of the situation was also made by the Federal Aviation Administration and in a May 10, 1971 letter to the U.S. Army Corps of Engineers they concluded that no situation exists which will derogate safety of either aircraft or vessel operations. This letter is reproduced as Supporting Document No. 3 at the end of this study.

aims

AMERICAN INSTITUTE OF MERCHANT SHIPPING

1120 Connecticut Avenue, N.W., Suite 930, Washington, D. C. 20036
Phone: 202/833-2710

Pacific Regional Office
635 Sacramento Street, Suite 300, San Francisco, California 94111
Phone: 415/362-7986

March 8, 1971

PROJECT ENGR.
PLANNING ENGR.
FILE

Col. Frank P. Bane
Division Engineer, New England Division
U. S. Army Corps of Engineers
424 Trapelo Road
Waltham, Massachusetts 02154

Dear Col. Bane:

PROPOSAL TO CONSTRUCT NEW RUNWAY AT
LOGAN INTERNATIONAL AIRPORT

This is in further reference to your notice of February 2, and the public hearing you held in Boston on February 26, with respect to application of the Massachusetts Port Authority for permit to fill in certain areas in Boston Harbor bordering the northeast side of Logan International Airport for the purpose of constructing a new runway to be designated 15L-33R. I attach copy of telegram which Mr. Reynolds, President of AIMS, sent you under date of February 25, which was read by Mr. John J. Halloran, Manager, Maritime Association of Greater Boston, at the hearing on February 26.

I enclose copy of letter dated February 22, which we received February 25, from Mr. Thomas H. Kuhn, Chief Engineer of the Massachusetts Port Authority, transmitting two drawings showing glide path elevations over President Roads Anchorage Area that would prevail for incoming planes landing on the proposed runway 15L-33R. These drawings which are quite large are not enclosed but I am sure Mr. Kuhn would send them to you at your request.

You will note that Mr. Kuhn makes the following statements in his letter:

> "The 3° glide slope shown on this plan is the average actual path of the aircraft approaching a runway. As an example, we have plotted a ship located in the northwest area of the anchorage with a 130-ft. mast which, in this particular case, at high tide would be 15 ft. clear of the 50 to 1 approach slope and 180 ft. clear of the glide slope of an aircraft approaching the runway. The areas of the anchorage outside the approach zone are less restrictive by FAA criteria and poses no problems whatsoever."

I inquired of Mr. Kuhn whether a plane would ever use the 50 to one approach slope for landing on the proposed new runway since according to MPA drawing #710222 if a plane used this approach slope it would clear the 130-ft. mast of a ship just within the northern limit of the President Roads Anchorage Area by only 15 feet at mean high water. Mr. Kuhn answered in the negative and stated that it would not be practicable for a plane to use the 50 to one approach slope for the purpose of landing on the end of the proposed new runway. Mr. Kuhn informed me that generally speaking, planes would follow the 3° glide slope in approaching the proposed new runway, thereby clearing the 130-ft. mast of a ship in the above location by about 180 feet. However, Mr. Kuhn did concede that under certain circumstances, such as poor visibility, storm, winds etc. incoming planes might approach the new runway on a glide slope below 3° which would reduce the clearance over the ship's mast below 180 feet. The reduction of such clearance could be considerable.

The above information was discussed by our Operations and Legal Committees at a joint meeting held in New York March 2. The Operations Committee consists for the most part of experienced navigators of ocean-going vessels of all types. This Committee with the concurrence of the Legal Committee concluded that a glide slope elevation of 180 feet or less, depending on circumstances, over a 130-ft. mast of a vessel was not adequate in the interest of safety and should be increased so that a safe margin of clearance would prevail under all circumstances.

Accordingly, the American Institute of Merchant Shipping requests that no permit be issued to the Massachusetts Port Authority for the purpose specified in your February 2 notice pending resolution of the glide path elevation problem as it relates to vessels in President Roads Acnhorage Area.

Sincerely,

O. Lincoln Cone

O. Lincoln Cone
Assistant Secretary

Enclosures (2)

CC: Messrs. Frank Fogarty, Chief, Operations Division
Thomas H. Kuhn
John Komich, FAA
Rear Adm. R. W. Goehring, Commander, First Coast Guard District

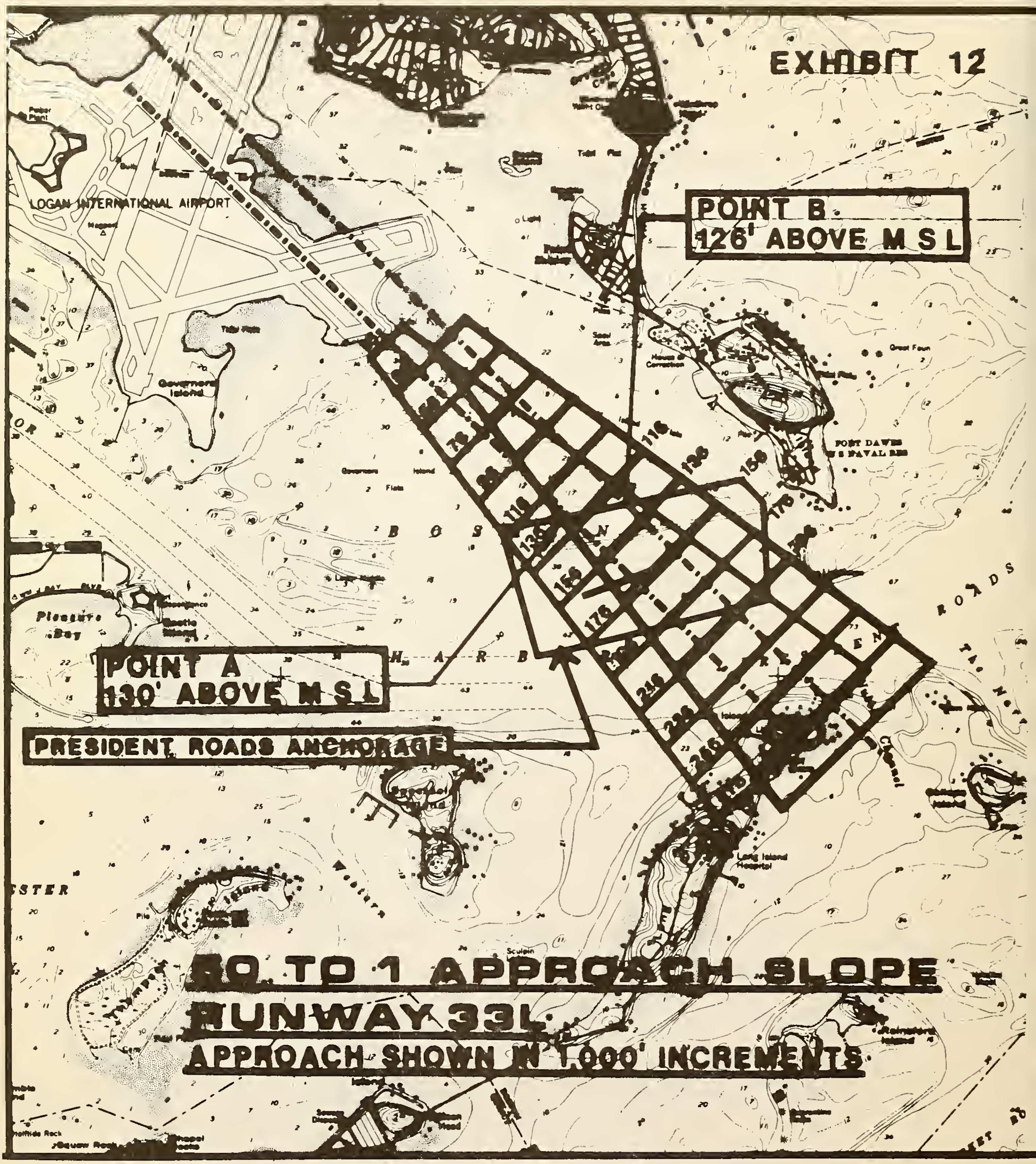


EXHIBIT 12
POINT B
126' ABOVE M S L
LOGAN INTERNATIONAL AIRPORT
POINT A
130' ABOVE M S L
PRESIDENT ROADS ANCHORAGE
50 TO 1 APPROACH SLOPE
RUNWAY 33L
APPROACH SHOWN IN 1,000' INCREMENTS

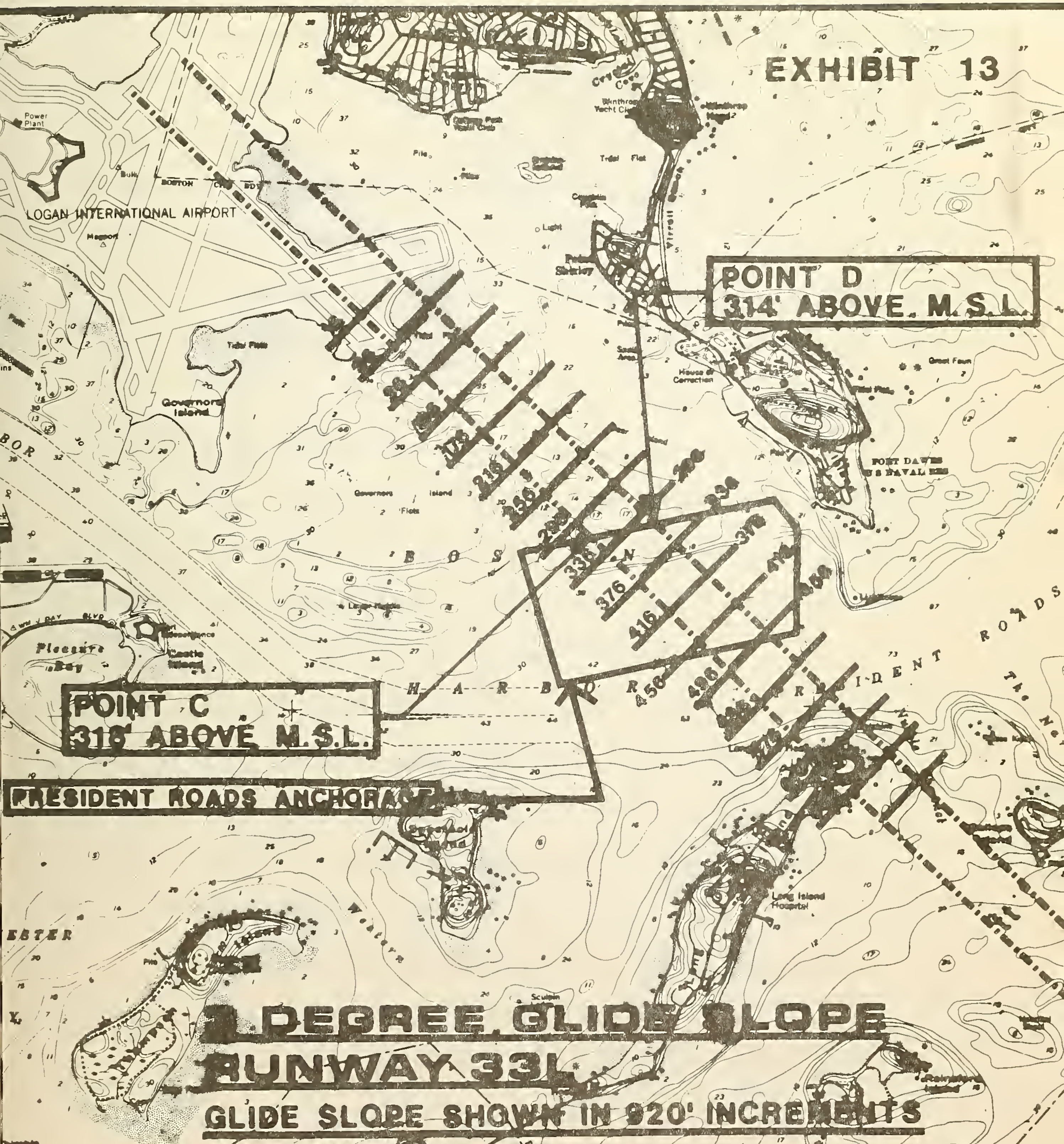


EXHIBIT 13
POINT D
314' ABOVE M.S.L.
POINT C
318' ABOVE M.S.L.
PRESIDENT ROADS ANCHORAGE
LOGAN INTERNATIONAL AIRPORT
Governors Island
Long Island Hospital
3 DEGREE GLIDE SLOPE
RUNWAY 33L
GLIDE SLOPE SHOWN IN 920' INCREMENTS

B. LASER DETECTION SYSTEM

Although means to provide improved approach zone protection over the main ship channel is not a part of the proposed airfield improvements, this subject was raised at the first Public Hearing concerning these improvements. The Massachusetts Port Authority is and has been actively engaged in technical projects aimed at improving operational safety and airport efficiency. One of these is a test program to establish the effectiveness and feasibility of a laser detection system.

1. Definition of Problem

a. The second longest runway at the Boston-Logan International Airport is Runway 4R and it is one of two equipped for instrument landings. Instrument weather at Logan usually occurs in conjunction with northeast winds, making 4R the principal runway used under these conditions. The physical layout of Runway 4R provides adequate obstruction clearance from permanent structures in the approach zones for instrument landings, using the full 10,000-foot runway length. However, a ship channel is located some 1,700 feet from approach end of the runway, and tall ships transiting this channel penetrate into the required obstruction clearance zones. Consequently, if IFR or night approaches for a landing near the physical end of Runway 4R were permitted, the possibility of a collision with a passing ship would be constantly present.

b. To offset this problem until a permanent solution could be found, the threshold for instrument approaches to Runway 4R was moved

2,500 feet from the approach end. Under VFR conditions (1,000 - ft. ceiling - 3-mile visibility), the use of the full length of Runway 4R is permitted during daylight hours. At night, the displaced threshold is used even under VFR conditions.

c. The need for a solution was obvious and a number of efforts were made to develop a detection system utilizing some type of radar or other electronic hardware. None of these efforts were fruitful due to technological inadequacies in meeting the positive detection and fail-safe requirements which the system demanded.

2. A Possible Solution

a. Late in 1970, the Massachusetts Port Authority entered into an agreement with the Massachusetts Institute of Technology's Lincoln Laboratory under which that group would conduct an experimental measurement program to establish the validity of a laser beam detection system. These tests will determine if such a system will permit utilization of the greatest possible length of Runway 4R for VFR traffic at night and provide a data base for a development program aimed at its eventual use for all weather operations

b. The design of a laser system to alert tower controllers of ships intruding into a protected area under VFR conditions is a problem of selecting the optimum devices and determining their best operational configurations. Of particular significance is the height at which the beam should be established to insure that all ships which constitute a threat are sensed, while the maximum number of other craft are permitted to pass undetected.

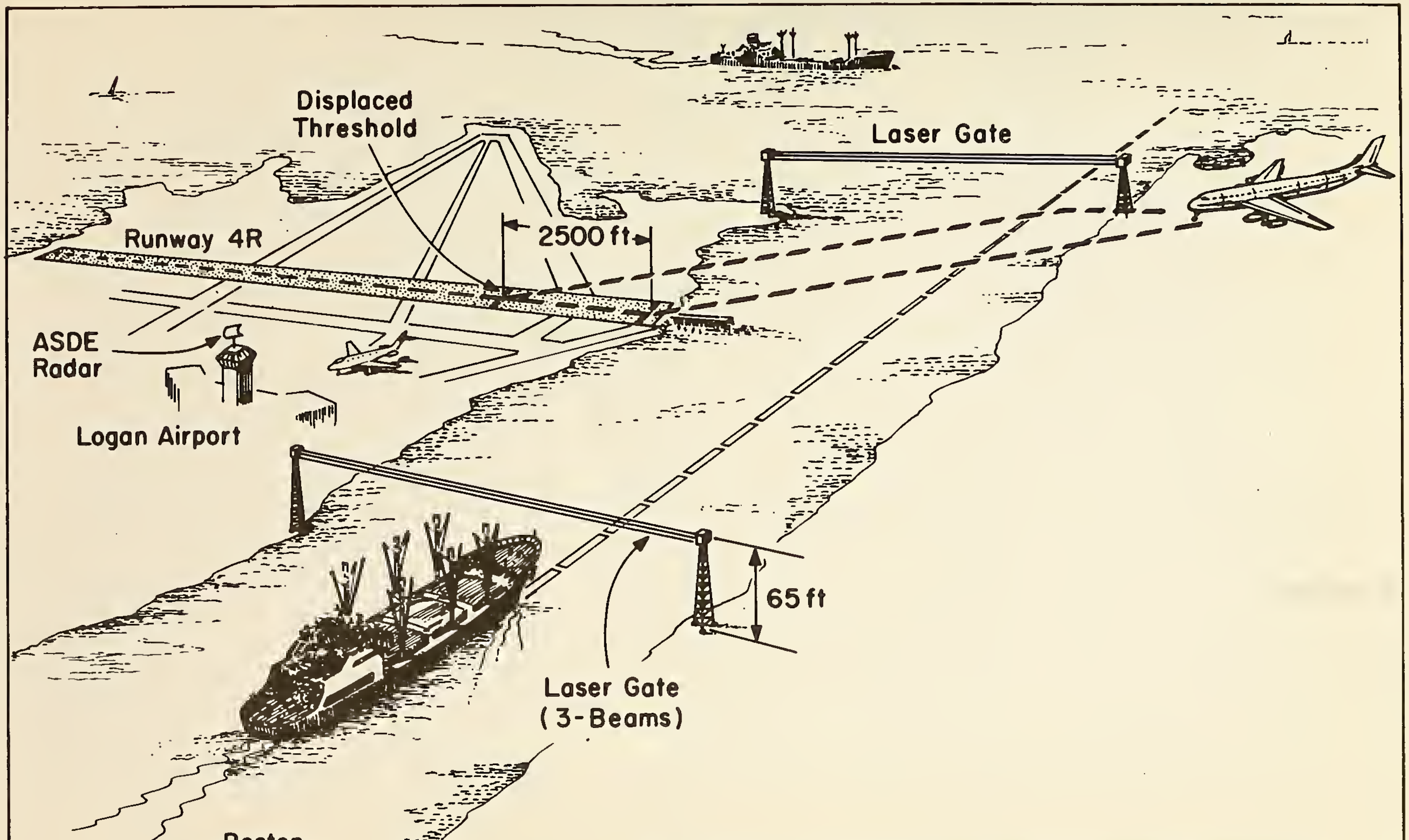
c. While many of the details of the experiment are still under study, the test contemplates the use of two essentially parallel beams spaced three to ten feet apart and possibly at slightly different elevations to minimize false alarms due to birds and to enable the sensing of ship movements, either up-channel or down-channel. (See Exhibit 14) A beam triggering circuit will be used to activate an automatic camera with a telephoto lens to photograph the object interrupting the beam. A low light level image intensifier system will also be used to provide similar photographic data at night.

d. Locations for the laser beam transmitters and receivers on both sides of the channel are presently being established and actual tests are scheduled for completion in July 1971.

e. If analysis of the data obtained indicates that the system meets all positive detection and fail-safe requirements and is acceptable to the Federal Aviation Administration, the Authority will proceed with the establishment of a permanent installation. Concurrently, a further developmental program will be initiated to investigate the feasibility of extending utilization of the system into instrument weather conditions

C. SAFETY ASPECTS OF AIRFIELD IMPROVEMENTS

In addition to providing greater capacity, operational flexibility and the opportunity for reductions in noise and air pollution, the airfield improvements proposed will contribute to an increase in operational safety margins.



A LASER SYSTEM FOR DETECTING SHIPPING
IN THE APPROACH ZONE AT LOGAN AIRPORT

EXHIBIT 14

1. <u>New Parallel Runway 15L-33R</u>

a. The potential hazard of wake turbulence created by large jet aircraft, upon following aircraft of less size and weight, has been well documented.

- This problem is most critical when all traffic must use a single runway.
- Parallel runway operation reduces the hazard since landing and takeoff operations are not normally combined on a single runway and physical separation between aircraft can be increased without creating delays.
- When capacity permits, aircraft operations which are not compatable in size and weight can be physically separated between the parallel runways.

b. The physical separation of landings on one runway and takeoffs of the other promotes operational safety in itself.

- With increased capacity, the problem of delay is minimized along with the minimum traffic separations which delay encourages.
- The necessity for "missed approaches" is reduced since landing aircraft will not be subject to departure aircraft which have not cleared the runway in time.

c. A parallel runway system provides an alternate runway in the same wind direction when one must be closed.

- Necessary runway closings can occur for a variety of reasons and frequently do.

- When a runway must be closed, the wind direction and velocity requires its use, and no parallel runway is available; traffic must either hold, be diverted to another airport or attempt the use of another runway, at least marginal with respect to crosswind.

2. <u>Extension of Runway 4L and 9</u>

   a. Increased runway length improves the margin of operational safety.

      - Additional length in which to stop in event of aborted takeoff.
      - Additional roll out length in event of long landings or mechanical malfunction.
        - Improvement in landing safety margins is applicable only to Runway 27, due to displaced thresholds on 4L and 9 and the landing restriction on 22R.

3. <u>STOL Runway 15-33</u>

   a. With a 5,000 ft. separation from the primary 15-33 runways, this facility also promotes operational safety when the 15-33 parallels are in use.

      - STOL Runway 15-33 can be utilized by a portion of general aviation traffic, independently of the main runway system.
        - Wake turbulence problems are essentially eliminated for those aircraft using the facility.
        - Mixing of incompatible aircraft types on the primary runway system, and the traffic patterns which serve it, is reduced.

APPENDIX D

SUPPORTING DOCUMENT
NO. 1

ANALYSIS OF AIR SERVICE EFFECTS

NIGHT CURFEW
at
BOSTON-LOGAN INTERNATIONAL AIRPORT

This document contains two summary sections (Exhibits II and IV) of a staff study on this subject dated December 12, 1969.

INTRODUCTION

The data developed on the following pages seeks to document the specific air service effects which would result should a complete curfew be established at Boston-Logan between the hours of 11 p.m. and 7 a.m. Flight schedules are further assumed to be terminated at 10:30 p.m. for inbounds and 10:50 p.m. for outbounds.

Sources of all schedule information are the Domestic and International quick reference editions of the "Official Airline Guide" dated September 1969. Schedules in effect during the first week of that month were used as the basic reference.

Effects of more frequent scheduling with future air traffic growth, additional cancellations and rescheduling in order to balance equipment and schedule time and pattern changes as new route authorizations are made could not be considered here but would have a very substantial additional effect, increasing with time.

CONTENTS

EXHIBIT II

SUMMARY OF BOSTON SCHEDULES DURING CURFEW PERIOD
(Per Week)

DOMESTIC PASSENGER FLIGHTS

Inbound	211
Outbound	74
Total	285

INTERNATIONAL PASSENGER FLIGHTS

Inbound	0
Outbound	4
Total	4

DOMESTIC CARGO FLIGHTS

Inbound	24
Outbound	45
Total	69

INTERNATIONAL CARGO FLIGHTS

Inbound	3
Outbound	9
Total	12

TOTAL FLIGHTS

Inbound	238
Outbound	132
Total	370

EXHIBIT IV

Summary

Air Service Effects of Boston Curfew

Schedules included in this analysis were those in effect during the first week in September 1969. Two assumptions are made in the following summary of air service effects:

1. All Schedules falling within curfew hours would be cancelled.

2. No additional schedules would be cancelled in order to balance equipment.

DOMESTIC PASSENGER FLIGHTS

Number of cities with scheduled service to or from Boston	162
Number of cities whose scheduled service would be affected	111
Percent of cities affected	69%

Seven cities would lose 100% of certain service.

Allentown	100% of all connecting service
Corpus Christi	100% of all service (thru & connecting)
Islip	100% of all connecting service
Lexington, Jy.	100% of all thru plane service
New Orleans	100% of all inbound thru plane service
San Diego	100% of all outbound thru plane service
Utica	100% of all outbound connecting service

Seven cities would lose 40% or more of total service outbound to Boston.

Augusta, Ga.	46%	Mobile	41%
Corpus Christi	100%	San Jose	65%
Elgin, AFB	61%	Wilkes Barre	50%
Liberty, N.Y.	53%		

Forty five cities would lose 20% or more of total service outbound to Boston. By geographic area these cities are located as follows:

Southeastern States	12	Pacific Coast	2
Northeastern States	7	Southwestern States	2
North Central & Midwest	7	Canada	2
South Central States	6	Mountain States	1
Mid Atlantic States	4	Carribean	1
		Mexico	1

Air Service Effects of Boston Curfew

Six cities would lose 20% or more of total service inbound from Boston.

Corpus Christi	100%	Pensacola	26%
Hartford	26%	Santa Barbara	22%
Manchester	30%	Worcester, Mass.	33%

Fifteen cities would lose 20% or more of all thru plane service outbound to Boston.

Buffalo	20%	Nashville	35%
Columbus	28%	Phoenix	55%
Corpus Christi	100%	Portland, Ore	50%
Denver	20%	Providence	37%
Ft. Lauderdale	20%	San Diego	100%
Lexington, Ky.	100%	Wilkes Barre	50%
Los Angeles	23%	Worcester, Mass.	24%
Louisville	25%		

Six cities would lose 20% or more of all thru plane service inbound from Boston.

Atlanta	33%	Manchester	30%
Corpus Christi	100%	New Orleans	100%
Hartford	25%	Worcester	33%

DOMESTIC CARGO FLIGHTS

Number of cities with scheduled service to or from Boston 23
Number of cities whose scheduled service would be affected 19
Percent of cities affected 83%

Twelve cities would lose 100% of total thru plane and connecting service in one or both directions.

Atlanta	100% of inbound service from Boston
Cincinnatti	100% of all service to and from Boston
Cleveland	100% of outbound service to Boston
Denver	100% of all service to and from Boston
Houston	100% of inbound service from Boston
Miami	100% of inbound service from Boston
New Orleans	100% of inbound service from Boston
Omaha	100% of all service to and from Boston
Orlando	100% of inbound service from Boston
St. Louis	100% of inbound service from Boston
Seattle	100% of all service to and from Boston
Portland, Ore.	100% of all service to and from Boston

All of the cities affected would lose 60% or more of total service inbound from Boston.

Thirteen of the cities affected would lose 20% or more of total service outbound to Boston.

Air Service Effects of Boston Curfew

INTERNATIONAL PASSENGER FLIGHTS

Number of cities with scheduled service to or from Boston. 105
Number of cities whose scheduled service would be affected. 63
Percent of cities 60%

Five Cities would lose 100% of total thru plane and connecting service inbound or outbound.

Bankok	100% of inbound service from Boston
Columbo	100% of inbound service from Boston
Santa Maria	100% of inbound service from Boston
Manila	100% of outbound service to Boston
Port Au Prince	100% of outbound service to Boston

Twenty eight cities would lose 20% or more of total service outbound to Boston. By geographic area these cities are located as follows:

South America, Central America & Bahamas	19
Europe	5
Far East	4
Total	28

Sixteen cities would lose 20% or more of total service inbound from Boston. By geographic area these cities are located as follows:

Europe	6
South America, Central America & Bahamas	5
Far East	2
Africa	2
Near East	1
Total	16

INTERNATIONAL CARGO

Number of cities with scheduled service to or from Boston 21
Number of cities whose scheduled service would be affected 12
Percent of cities affected 57%

Five cities would lose 100% of all service inbound and outbound

Ankara	Shannon
Cologne	Vienna
Munich	

One city, Stuttgart, would lose 100% of all service inbound from Boston.

Ten out of the twelve cities affected would lose 50% or more of total service to and from Boston.

APPENDIX D

SUPPORTING DOCUMENT NO. 2

Fay, Spofford & Thorndike, Inc.

Environmental Report
Runway 15L-33R
Boston-Logan International Airport

FAY, SPOFFORD & THORNDIKE, INC.
ENGINEERS

11 BEACON STREET • BOSTON, MASSACHUSETTS 02108
(617) 523-8300

MASSACHUSETTS PORT AUTHORITY ENGINEERING DEPARTMENT		INITIALS
CHIEF ENGINEER	✓	TAK
DEPUTY CHIEF ENGR	✓	
PORT ENGINEER		
ELECT. MECH ENGR.		
PROJECT ENGR.		
PLANNING ENGR.	✓	
FILE		

May 7, 1971

Mr. Thomas H. Kuhn, Chief Engineer
Massachusetts Port Authority
470 Atlantic Avenue
Boston, Massachusetts 02110

Subject: Environmental Report
Runway 15L-33R
Boston-Logan International Airport

Dear Sir:

In accordance with your request of April 8, 1971, we have been in contact with representatives of the Corps of Engineers with regard to the ecological effects of the materials specified for the construction of the dikes and the fill behind the dikes for the proposed new runway 15L-33R. After a review of the specifications and drawings for MPA Contract No. 1.100 and the specifications for MPA Contract No. 1.103, it was the consensus of the meeting that the material would not cause any serious threat of pollution to the water in the area as long as the specifications were carefully adhered to. It was further felt that if some of the fines from the fill material did find their way beyond the limits of the dike, they would settle out rapidly and not remain in suspension for a long period of time. There was some discussion as to the source of the material and method of delivery to the site. It was explained that this could not be determined at this time but that it could be by train, train and truck, train and conveyor, train and hydraulic pumping, by barge or by truck or any combination thereof. The materials are available within an area from 10 to 100 miles of Boston and we presume local ordinance will regulate the source.

It is our opinion therefore that the proposed design of the dike and the specified fill material will not be objected to by the Corps of Engineers when evaluating the effect of the new runway on the airport area ecology.

With regard to the other items mentioned at the meeting on April 8, 1971, we report as follows:

FAY, SPOFFORD & THORNDIKE, INC
ENGINEERS
BOSTON, MASS.

1. Disposal of Dredged Material

Requests for a permit to dispose of dredged material at sea will still be made to the Corps of Engineers. The request for the permit must include a chemical analysis of the soil to be disposed of. If the Corps of Engineers can obtain approval from the Environmental Protection Agency, they will grant a license to dispose of the material at sea. If requested, the Corps will also designate the area in which the material may be dumped. Chemical analyses of the soil to be dredged for the construction of the dike are attached. A comparison of the summary of the tests against the percentage of elements for which limits have been set by the Federal Environmental Protection Agency Water Quality Office as Criteria for Determining the Acceptability of Dredged Spoil Disposal to the Nation's Water, indicates the material is relatively clean and may qualify for disposal at sea even though it exceeds the permissible nitrogen and the relationship between the volatile solids and the chemical oxygen demand does not meet the EPA formula. In discussing the relatively high chemical oxygen demand in relation to the volatile solids with the Laboratory that made the tests, it was stated that the EPA formula was apparently based on the assumption that only organic material would have a chemical oxygen demand whereas inorganic material may also have a chemical oxygen demand. It is interesting to note that the deeper samples at each test point had an appreciable larger chemical oxygen demand than those closer to the surface.

If disposal at sea is not permitted, disposal may be made by hydraulic or other suitable means on Airport Property in the water area between North Taxiway and Runway 22L-4R and 15L-33R. Suitable control structures will have to be constructed to assure that the amount of solids in the effluent from the area meets whatever Federal Criteria that may be established. This can be accomplished by retention in settling ponds and the construction of weirs and baffles.

The laboratory tests for settleability indicates that the material does not remain in suspension for a long period of time. If disposed of at sea, the material would not be carried far from the area in which is was dumped. If disposed of on land, treatment of effluent water to reduce solids to an acceptable minimum should not be difficult.

2. Aesthetics of Rock Embankment

Aesthetics is one of many things that is normally considered in the design of any structure exposed to public view. There must be a balance between aesthetics, economy of construction, economy of maintenance, and the ability of the structure to perform its functions with efficiency with the least adverse effect on its surroundings. The possible structures that could be used to retain the fill material are as follows:

(a) A timber bulkhead;

(b) A steel sheet pile bulkhead;

(c) A structural concrete retaining wall;

(d) A stone riprap face on an earth or stone fill.

For a waterfront structure which does not require a vertical face for the docking of vessels and where space permits, we consider a sloping surface to be desirable. A sloping face permits waves and the wash from boats and ships to dissipate without causing a counter wave. Vertical surfaces reflect waves and the wash from boats operating in the area which can be dangerous to the operation of small boats. It also provides an access to land for swimmers who might capsize in small boats in the area.

Timber bulkheads have a limited life, require constant maintenance and ultimate replacement. Timber bulkheads originally constructed at the airport had to be protected with stone riprap to prevent their total collapse.

Steel sheet pile bulkheads require maintenance often including electronic protection, are not inexpensive and in our opinion present a poor appearance.

Concrete retaining walls are expensive and the life of concrete exposed to tidal action is limited. In addition a review of concrete structures in the area indicates staining from the contaminated water which detracts from their appearance.

The New England area is no stranger to rock outcrops facing the ocean. A rock dike or a rock protected earth fill is no more expensive to construct than any of the other types; maintenance is nominal and there are instances of such installation in the area which are older than living memory. In our opinion, they present a pleasing appearance, which blends with the New England scene. Because they appear to satisfy all criteria, they were chosen for this project.

3. Rat Problems

It has been stated that stone riprap protected slopes are an invitation to infestation by rats. Experience with rat control indicates that where there is no food supply there are no rats. If there are rats currently living in the area in which the stone structure will be constructed, they undoubtedly will take up living in the interstices in the stone. The stone offers no food supply so the rat population should not increase. Adequate rat control programs are available and, if rats should become a problem, they can be controlled.

Very truly yours,

FAY, SPOFFORD & THORNDIKE, INC.
By

W J Hallahan
W. J. Hallahan

WJH:hcd
Attachments
Summary of Chem.Tests
Skinner & Sherman, Inc., Technical Report
dated May 6, 1971

OB-35

FAY, SPOFFORD & THORNDIKE, INC
ENGINEERS
BOSTON, MASS.

May 7, 1971

SUMMARY

OF

CHEMICAL TESTS ON MUD TO BE DREDGED

Environmental Protection Agency Dredging Criteria

Item	Limit % Dry Weight	% Samples Logan Mud
Volatile Solids	6%	2.93%
Chemical Oxygen Demand (C.O.D.)	5%	4.42%
Total Kjeldahl Nitrogen	0.10%	0.12%
Oil-Grease	0.15%	0.016%
Mercury	0.0001%	0.000077%
Lead	0.005%	
Zinc	0.005%	0.000085%

SKINNER & SHERMAN, INC.
NEW ENGLAND LABORATORIES, INC.
227 CALIFORNIA ST., NEWTON, MASSACHUSETTS 02195 • 617-332-8300

Chemical Service and Testing for Industry

TECHNICAL REPORT

May 6, 1971

CLIENT: Fay, Spofford & Thorndike, Inc.
11 Beacon Street
Boston, Massachusetts 02108

Attention: Mr. W. J. Hallahan

CASE NO. 2280

PURPOSE OF TEST: Chemical analysis of nine (9) samples of "Sea Mud"

SAMPLE IDENTIFICATION:

A-S#1	29+00	0 to 50'
A-S#2	99+00	14 to 17'
B-S#1	25+00	0 to 5' press
B-S#2	25+00	15 to 17' press
C-S#1	20+00	0 to 2' press
C-S#2	20+00	15 to 17' press
D-S#1	15+10	0 to 26' press
D-S#2	15+00	9 to 11' press
E-	10+00	0 to 2' 6" push

RESULTS:

All results were obtained on oven dry basis (dried at 105°C.).

	A S#1	A S#2	B S#1	B S#2	C S#1	C S#2	D S#1	D S#2	E S#1
olatile Solids, %	1.57	3.48	1.27	5.12	3.80	1.60	4.95	2.48	2.10
.O.D., %	5.40	9.96	3.46	8.64	3.92	3.30	2.20	2.20	.70
otal Kjeldahl Nitrogen, %	0.15	0.16	0.14	0.12	0.10	0.10	0.13	0.10	0.08
il-Grease, %	0.014	0.023	0.018	0.020	0.015	0.020	0.016	0.009	0.009
ercury, ppm	0.46	0.18	0.28	0.23	1.43	0.54	0.69	0.36	2.77
inc, ppm	0.88	0.09	0.93	1.43	0.10	1.48	0.10	0.08	2.58
admium, ppm	0.29	0.18	0.08	0.13	0.01	0.44	0.19	0.15	0.30
opper, ppm	50.0	42.0	46.0	54.0	8.5	18.0	11.0	12.0	13.0

TECHNICAL REPORT

May 6, 1971

Fay, Spofford & Thorndike, Inc.
Case No. 2280

	A S#1	A S#2	B S#1	B S#2	C S#1	C S#2	D S#1	D S#2	E S#1
'senic, ppm	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
ıromium, ppm	160.0	180.0	130.0	170.0	46.0	62.0	42.0	45.0	45.0
.lver, ppm	20.0	12.0	7.0	11.0	5.0	6.0	2.0	2.0	5.0
;tleability %*	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
)latile Solids :.O.D. ratio	6.61	11.05	4.71	9.78	5.16	4.55	3.47	3.47	2.00

)ne ml of dried material was dispersed in 1 liter of water and allowed to settle in an Imhoff cone. All the material settled within 15 minutes.

J.D. = Not detected, less than 5ppm

Respectfully submitted,

SKINNER & SHERMAN, INC.

Robert A. Sullivan

Robert A. Sullivan
President

\S:js

FAY, SPOFFORD & THORNDIKE, INC.

ENGINEERS

11 BEACON STREET • BOSTON, MASSACHUSETTS 02108
(617) 523-8300

May 17, 1971

Mr. Thomas H. Kuhn, Chief Engineer
Massachusetts Port Authority
470 Atlantic Avenue
Boston, Massachusetts 02110

Subject: Environmental Report
Boston-Logan International Airport

Dear Sir:

Transmitted herewith is a copy of a report showing the lead found in the samples of mud to be dredged taken from the proposed dike area for Runway 15L-33R.

This should be added to our report dated May 7, 1971, and the blank left on the Summary Sheet for PPM of lead found in the Samples Logan Mud should be filled in figure 0.000053.

To the best of my knowledge, this completes our work on the Environmental Report.

Very truly yours,

FAY, SPOFFORD & THORNDIKE, INC.
By

W. J. Hallahan

WJH: hcd
Attach

OB-35

		INITIALS
CHIEF ENGINEER		
DEPUTY CHIEF ENGR.		
PORT ENGINEER		
ELECT. MECH. ENGR.		
PROJECT ENGR.		
PLANNING ENGR.		
FILE		

SKINNER & SHERMAN, INC.
NEW ENGLAND LABORATORIES, INC.
227 CALIFORNIA ST., NEWTON, MASSACHUSETTS 02195 • 617-332-8300

Chemical Service and Testing for Industry

TECHNICAL REPORT , May 14, 1971

CLIENT: Fay, Spofford & Thorndike, Inc.
11 Beacon Street
Boston, Massachusetts 02108

Attention: Mr. W. J. Hallahan

CASE NO. 2280

PURPOSE OF TEST: Chemical analysis of nine (9) samples of sea mud for lead content.

METHOD OF TEST: Atomic absorption

RESULTS:

Sample Marked			Lead as Pb ppm	Lead as Pb, %
A-S #1	29+00	0 to 50'	1.47	.00015
A-S #2	99+00	14 to 17'	0.36	.000036
B-S #1	25+00	0 to 5' press	0.31	.000031
B-S #2	25+00	15 to 17' press	0.26	.000026
C-S #1	20+00	0 to 2' press	0.58	.000058
C-S #2	20+00	15 to 17' press	0.70	.000070
D-S #1	15+10	0 to 26' press	0.77	.000077
D-S #2	15+00	9 to 11' press	0.15	.000015
E	10+00	2 to 2' 6" push	0.15	.000015

Respectfully submitted,

SKINNER & SHERMAN, INC.

Robert A. Sullivan

Robert A. Sullivan
President

RAS:js

Subsidiaries of RAHN corporation

APPENDIX D

SUPPORTING DOCUMENT
NO. 3

LETTER FROM FEDERAL AVIATION ADMINISTRATION
TO
U.S. ARMY CORPS OF ENGINEERS
10 MAY 1971

(Analysis of Approach Slopes Over President Roads Anchorage)

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

NEW ENGLAND REGION
154 Middlesex Street
Burlington, Massachusetts 01803

Telephone 617 223-2271

10 May 1971

Mr. F. W. Fogarty
Chief, Operations Division
N. E. Division Corps of Engineers
424 Trapelo Road
Waltham, Massachusetts 02154

Dear Mr. Fogarty:

We have reviewed the comments contained in your communication of 15 March 1971 and also those cited by Mr. Cone and Mr. Reynolds in their correspondence of 8 March 1971 and 25 February 1971 respectively.

I believe you have assessed the situation concerning the President Roads anchorage and the approach to proposed runway 33R very well by stating that it is, "more a question of aircraft safety rather than vessel safety." As you are well aware a primary function of the FAA is to insure aviation safety. We have evaluated the utilization of this anchorage by maritime vessels and do not feel that a condition exists which will derogate the safety of either aircraft or vessel operations. In making this assessment safety has not been compromised.

Landing procedures which the FAA will develop and publish will consider the physical environment of this approach and insure safe aircraft operations. The guidelines adopted to design and standardize these procedures are defined in a Federal publication entitled, "United States Standard for Terminal Instrument Procedures" (TERPS).

The approach to runway 33R will ultimately have an Instrument Landing System (ILS) which is defined by our criteria as a precision approach. The vertical descent guidance provided by the Glide Slope (GS) facility will probably be set at a 3° angle. The required obstacle clearance slope associated with a 3° GS within the final 10,000 feet of this approach is 34:1. Both of these gradients and their relative position with respect to the anchorage is depicted on the enclosed sketch. The difference between the two planes represents the "cushion" or as it is defined in TERPS, the "Required Obstruction Clearance" between the actual descent path of the aircraft and the obstacle clearance plane. You will note that a vessel with a mast height of 130' located at the most critical area in the approach zone does not encroach into the 34:1 and is approximately 180' below the GS.

Mr. Cone in his letter of 8 March has expressed concern with aircraft flying below the GS. To allay his fears in this regard, we refer to the Federal Aviation Regulations (FAR), Part 91, General Operating and Flight Rules, paragraph 91-87:

> A turbine-powered airplane or a large airplane approaching to land on a runway being served by an ILS, shall, if the airplane is ILS equipped, fly that airplane at an altitude at or above the glide slope between the outer marker and the middle marker.

For the most part all aircraft utilizing the airport are ILS equipped. Those who are not will not be utilizing the airport during low operating minimums. A pilot operating in violation of these regulations could be subject to sanction.

The sketch enclosed with this correspondence shows the 50:1 surface with the area shaded in red indicating penetrations by a vessel with a 130' mast. Although this could be classified as an obstruction, it is not considered a hazard to aircraft operations and it will not affect either operating minimums or procedures which are established utilizing the TERPS manual.

We trust this information presented herein has helped to alleviate some of the concern which the Maritime Institute of Merchant Shipping has expressed. We reiterate, this agency is well aware of the conditions which exist in this approach and would not consider operations which derogate safe operating procedures. If it would be of any further assistance, we are available to discuss with your staff and Maritime Institute of Merchant Shipping representatives the various parameters involved in evaluating the approach surfaces.

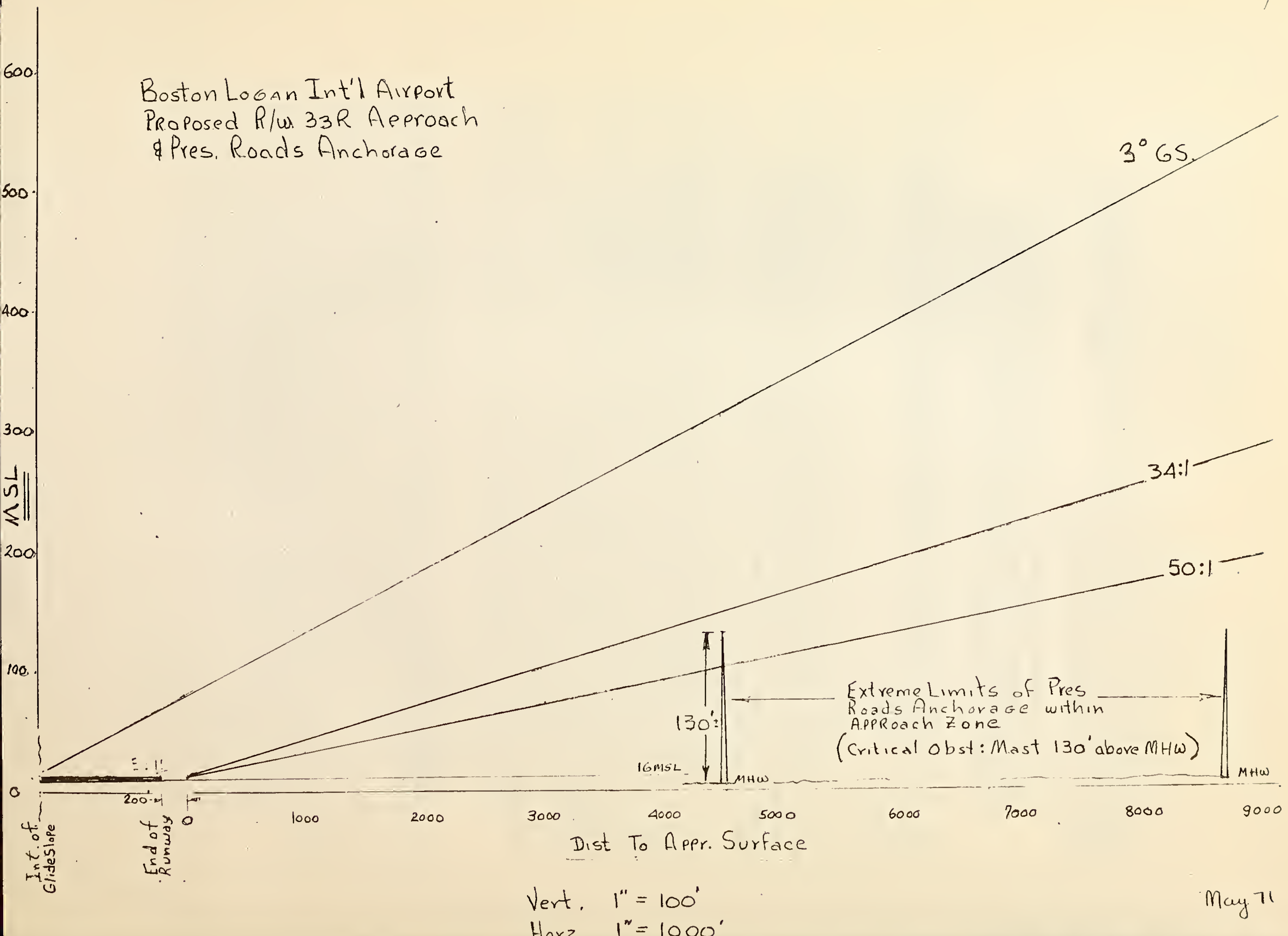
Sincerely,

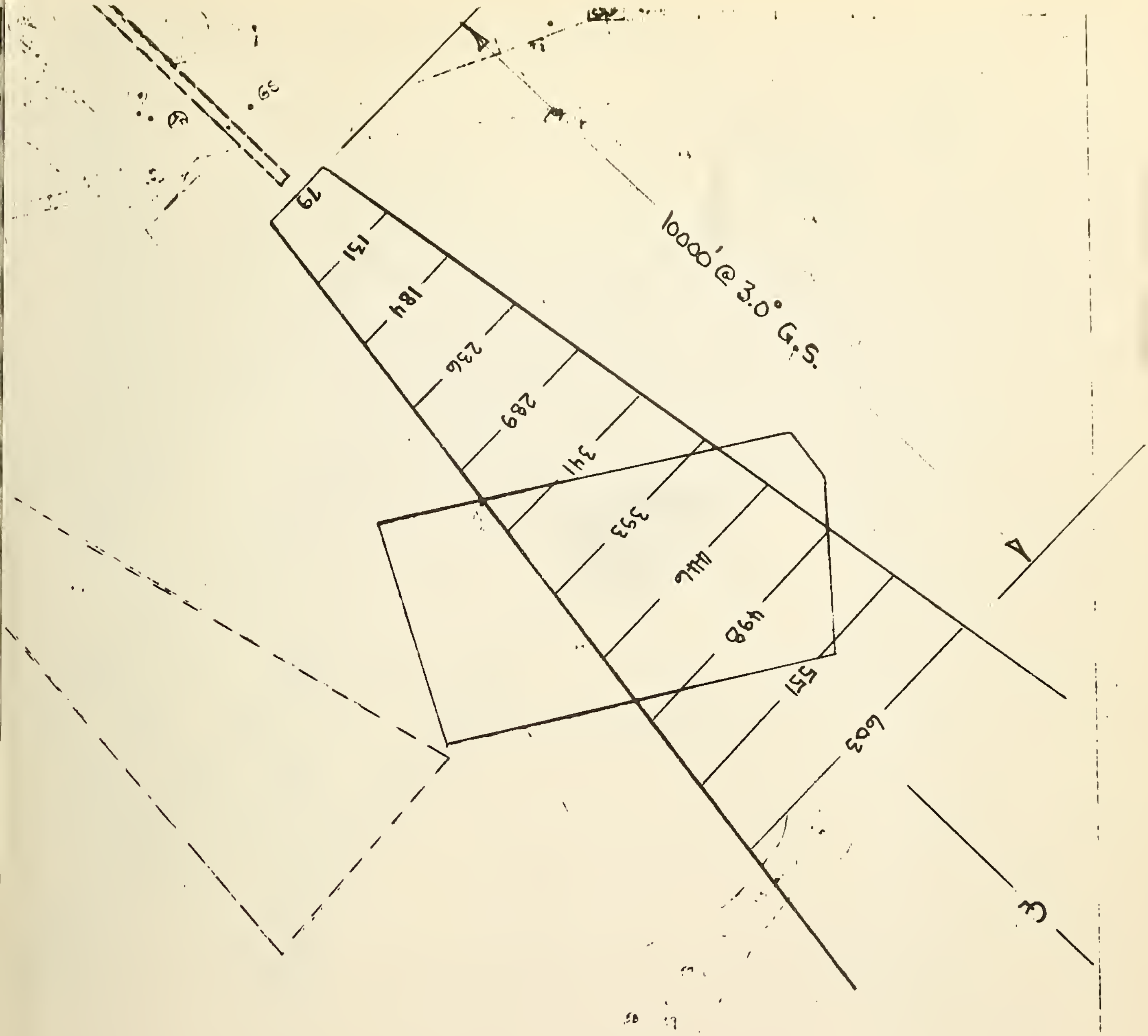
ORIGINAL SIGNED BY
JOHN B. KOMICH

J. B. KOMICH
Acting Chief, Airports Division, NE-600

Enclosure

cc:
Mass. Port Authority (Mr. Bender) w/encl


Boston Logan Int'l Airport
Proposed R/W 33R Approach
& Pres. Roads Anchorage
600
500
400
300
MSL
200
100
0
3° GS.
34:1
50:1
130'
16 MSL
MHW
MHW
Extreme Limits of Pres Roads Anchorage within Approach Zone
(Critical Obst: Mast 130' above MHW)
200
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Int. of GlideSlope
End of Runway
Dist To Appr. Surface
Vert. 1" = 100'
Horz. 1" = 1000'
May 71

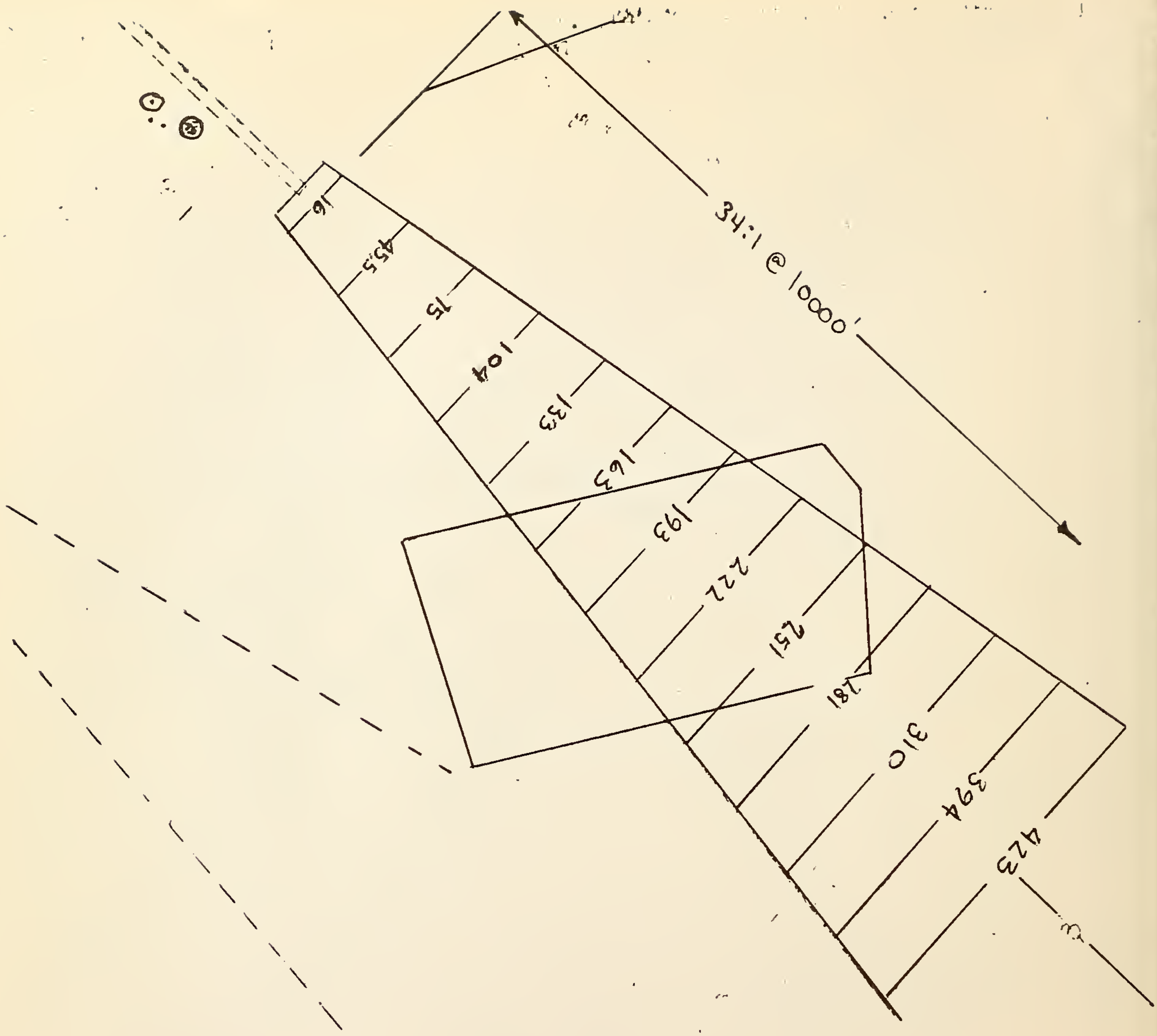


Boston Logan Int'l Airport
Proposed R/W 33R Approach
& President Roads Anchorage

MSL Elv. @ 3.0° Glide Slope

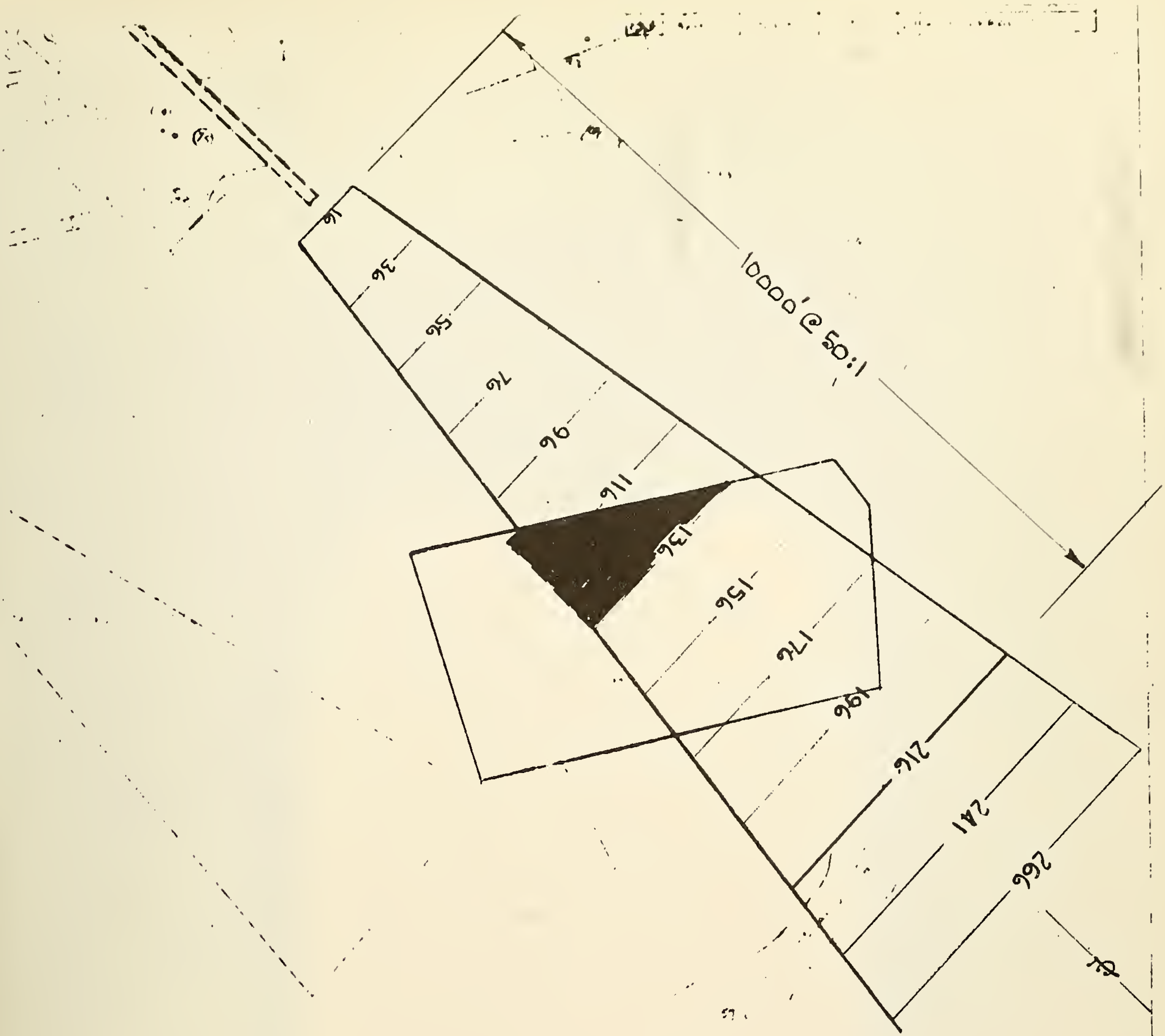
7 May 71

Sh 2/4



Boston Logan Int'l Airport
Proposed R/W 33R Approach
& President Roads Anchorage
MSL Elv @ 34:1 Slope (Req'd for 3° G.S.)

May 71



Boston Logan Int'l Airport
Proposed R/W 33R Approach
& President Roads Anchorage

MSL Elv. @ 50:1 — Penetration to 50:1 —

sh 4/4

7 May 71